SPIE. MICRO+NANO MATERIALS, DEVICES, AND APPLICATIONS

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MICRO+NANO MATERIALS, DEVICES, AND APPLICATIONS.

TECHNICAL SUMMARIES

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The University of Sydney
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9668-500, Session Plen

Strong interaction between photons, phonons, and electrons enabled by silicon photonics

Michal Lipson, Columbia Univ. (United States)

Recent advances in silicon photonic led the demonstration of unique high quality structures that support photonic, phononic and electronic modes. For example, suspended ultra-high Q structures act as high confinement for both optical modes in the NIR and vibrational modes in the RF, and specially designed structures act as traveling waves for both optical and electrical modes in the microwave. The strong interaction between these different modes across the electromagnetic spectrum lead to novel fundamental phenomena. We have recently demonstrated that strong interaction between light and optical phonons in suspended structures can lead to near-field radiative cooling of a thermally isolated nanostructure. Strong interaction between light and acoustic phonons can lead to synchronization of mechanical structures. Finally strong interaction of light and electrical fields can lead to optical non-reciprocity.

9668-503, Session Plen

Silk biomaterials: a life on the edge

Fiorenzo G. Omenetto, Tufts Univ. (United States)

Biomaterials offer opportunities for devices that operate seamlessly at the interface of the biological and technological worlds. Stringent requirements on material form and function are imposed when operating at the nanoscale or when interfacing such materials with microelectronic circuitry. Silk fibroin is a very attractive biopolymer for use as the starting point for nanostructured optical materials and thin-film electronics. Devices such as silk-based photonic crystals, lasers, wireless antennas and resorbable electronics will be described as some examples of the possibilities that this water-processed, biocompatible material offers.

9668-1, Session 1A

Recent progress in the physics of hyperbolic, all-dielectric and nonlinear metamaterials *(Invited Paper)*

Yuri S. Kivshar, The Australian National Univ. (Australia)

We will review the recent advances in the physics of metamaterials, metasurfaces and metadevices. In particular, we will discuss multilayer fishnet metamaterials with magnetic hyperbolic dispersion, all-dielectric nanostructures composed of high-permittivity dielectric nanoparticles, metasurfaces and associated planar metadevices, and also the most recent studies of nonlinear effects in all-dielectric nanophotonic structures and metadevices. The examples will demonstrate the importance of optically-induced magnetic resonances and optical magnetism for creating a new generation of functional photonic devices employing the concept of metamaterials and metasurfaces.

9668-3, Session 1A

Magnetic hyperbolic metamaterials

Sergey S. Kruk, The Australian National Univ. (Australia); Zi Jing Wong, Univ. of California, Berkeley (United States); Ekaterina Pshenay-Severin, Friedrich-Schiller-Univ. Jena (Germany); Kevin O'Brien, Univ. of California, Berkeley (United States); Dragomir N. Neshev, Yuri S. Kivshar, The Australian National Univ. (Australia); Xiang Zhang, Univ. of California, Berkeley (United States)

Strongly anisotropic media, where the principal components of the dielectric permittivity and/or permeability tensor have opposite signs, are called hyperbolic media. The study of hyperbolic media and hyperbolic metamaterials have attracted significant attention in recent years for their interesting properties such as high density of states, all-angle negative refraction, and hyperlens imaging beyond the resolution of conventional systems. In previous studies hyperbolic media were realized as uniaxial materials whose axial and tangential dielectric permittivities have opposite signs. Such media are typically realized using the metamaterial concept in the form of metal-dielectric multilayered structures, or arrays of conducting nanowires, while several examples of natural hyperbolic media have been demonstrated as well. However, the hyperbolic dispersion in all artificial and natural optical media demonstrated to date has its origin in the electric response. This restricts fundamentally the functionality of these materials for only one polarization of light and places severe limitation for the impedance matching with a free space. Importantly, the concept of generalized hyperbolic media with both electric and magnetic response does not have these restrictions. Here we present the first demonstration of a magnetic hyperbolic dispersion in a three-dimensional optical metamaterial with principal components of the effective magnetic permeability tensor having opposite signs. We provide a systematic direct measurement of a topology-driven transition between elliptic and hyperbolic metamaterials observed through a structural modification of their dispersion, reported for the time for any type of metamaterial. Our findings show the possibility for realization of efficient hyperbolic media for unpolarised light.

9668-5, Session 1A

Dynamic tuning and switching of all-dielectric metasurfaces with liquid crystals

Juergen Sautter, The Australian National Univ. (Australia); Isabelle Staude, The Australian National Univ. (Australia) and Friedrich-Schiller-Univ. Jena (Germany); Manuel Decker, Evgenia Rusak, Dragomir N. Neshev, The Australian National Univ. (Australia); Igal Brener, Sandia National Labs. (United States); Yuri S. Kivshar, The Australian National Univ. (Australia)

All-dielectric metasurfaces allow for controlling wavefronts at the nanoscale with near-unity efficiency [1] and, therefore, are a promising candidate for practical applications. Thus, the possibility of dynamically controlling their optical properties becomes increasingly important. For plasmonic metasurfaces, tuning mechanisms based on liquid crystals (LCs) [2] utilizing either the strong temperature dependence of the LC optical anisotropy or their realignment in an external electric field have been extensively explored. However, to date dynamic control of all-dielectric metasurfaces remains an open challenge and experimental realizations are still missing.

In our work we use a silicon-nanodisk metasurface featuring strong electric- and magnetic-dipole resonances. The metasurface is integrated into a 170μm-thick LC-cell with 'Licristal E7' LC from Merck featuring a strong optical anisotropy along the axis of the LC molecules in its nematic phase. To demonstrate dynamic resonance tuning originating from the temperature-dependent refractive-index change of the LC in the nematic phase we record the sample's transmission with increasing LC temperature and obtain a maximum spectral tuning range of approximately 40 nm with a maximum relative transmittance change of up to a factor of 5. Furthermore, switching from the nematic LC phase to the isotropic phase and back (at T = 58°C) allows us to induce or remove the optical isotropy of the metasurface response. Our experimental observations are in excellent agreement with numerical simulations.

References:

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[2] Khoo et al., IEEE J. Sel. Top. Quantum Electron, 16, 410 (2010).

9668-22, Session 1A

Nonlinear torsional metamaterials

Mingkai Liu, David A. Powell, Ilya V. Shadrivov, The Australian National Univ. (Australia); Mikhail Lapine, Univ. of Technology, Sydney (Australia) and Univ. of Sydney (Australia); Yuri S. Kivshar, The Australian National Univ. (Australia)

Full spatial control of metamaterials, especially at infrared and optical frequencies, is not a trivial task. The hybridization of metamaterials and optomechanics could provide a scalable approach to address this problem, and we present several results in this direction. Inspired by the pioneering work on magnetoelastic metamaterials [1], we introduce the idea of torsional meta-molecule that allows much more sensitive elastic feedback and stronger optomechanical interaction. The chiral nature of the structure induces strong electromagnetic torque, which can be used to change the twist angle of the meta-molecule. We predict and verify experimentally strong stationary nonlinear effects such as self-tuning and bistability [2] at microwave frequencies. The interaction of meta-atoms can also have a significant impact on the system stability. For a torsional meta-molecule with more than one degree of freedom, we predict nontrivial dynamic phenomena including damping-immune self-oscillations and dynamic nonlinear optical activity [3]. This is a special situation when all the equilibrium points of the system become unstable, and the structure can develop a limit-cycle even though the mechanical damping is extremely large. Recently, we explored the nonlinear effect of a system comprising enantiomeric torsional chiral meta-molecules [4]. Due to the inter-molecular interaction, the system stability changes and as such the original chiral symmetry can be broken spontaneously when the pump power surpasses certain thresholds, leading to mode splitting and strong nonlinear optical activity.

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9668-6, Session 1B

From smartphones to diagnostics: programmable droplet microfluidics *(Invited Paper)*

Hywel Morgan, Univ. of Southampton (United Kingdom)

Our group is developing integrated analytical systems for healthcare and medicine that utilize inexpensive electronics for sample detection and manipulation. Such systems will find applications as tools for life science and in new diagnostics for molecular and cellular analysis. This talk describes the development of a new generation of programmable miniature microfluidic systems, based on digital microfluidics. Unlike conventional microfluidic systems that require pumps and valves to control liquids, digital microfluidics (DMF) employs Electro Wetting on Dielectric (EWOD) to manipulate and process nanolitre droplets of liquid using electric fields. The chips contain thousands of electrodes, manufactured using active matrix Thin Film Transistor (TFT) technology, the same low cost electronics that are used in mobile phone displays. The devices are the size of microscope slides and contain thousands of individual electrodes, each of which can be programmed separately. Each electrode can be switched on and off independently allowing many droplets to be manipulated in parallel, providing an extremely flexible platform that enables the development of automated custom diagnostic assays. The DMF chips include sensors to measure droplet position and droplet volume, providing feedback control to automatically verify and validate successful operation. The systems support a wide range of different chemical and biochemical assays, for example immuno-assays and DNA analysis. Further examples of low-cost electronic systems for analyte and cell detection will be given, including impedance based cytometry and Si nano-wire biosensors made using simple fabrication methods.

9668-7, Session 1B

Computation and simulation with microorganisms in microfluidics

Dan V. Nicolau, McGill Univ. (Canada)

Many important problems, e.g., cryptography, network routing, require the exploration a large number of candidate solutions. Because the time required for solving these problems grows exponentially with their size, electronic computers, which operate sequentially, cannot solve them in reasonable timeframe. Unfortunately, the parallel-computation approaches proposed so far, e.g., DNA-, and quantum-computing, suffer from fundamental and practical drawbacks, which prevented their implementation. On the other hand, biological entities, from microorganisms to humans, process information in parallel, routinely, for essential tasks, such as foraging, searching for available space, competition, and cooperation. However, aside of their sheer complexity, parallel biological processes are difficult to harness for parallel computation because of a fundamental difference: biological entities process analog information, e.g., concentration gradients, whereas computing devices process numbers.

Two major classes of motile, self-propelled biological agents could be envisaged: protein linear molecular motors, where cytoskeletal filaments, such as actin filaments or microtubules are propelled by surface-immobilized molecular motors, such as myosin or kinesin, respectively; and microorganisms, such as fungi, motile bacteria and algae. While the technology involving the use of molecular motors-propelled agents advanced steadily in the last two decades, fungi and bacteria are also natural choices for the exploration of microfluidics networks encoding mathematical problems. For instance, the growth behaviour and optimality of space-searching algorithms of several fungal species has been tested in microfluidic mazes and networks. First, it was found that the growth behaviour of all species was strongly modulated by the geometry of micro-confinement. Second, the fungi used a complex growth and space-searching strategy comprising two algorithmic subsets: (i) long-range directional memory of individual hyphae and (ii) inducement of branching by physical obstruction. Third, stochastic simulations using experimentally measured parameters showed that this strategy maximizes both survival and biomass homogeneity in micro-confined networks, producing optimal results only when both algorithms are synergistically used.

The presentation conclude with an overview the several research directions regarding the computation and simulation using biological entities in microfluidics structures, weighing the opportunities and challenges offered by various technological avenues.

9668-8, Session 1B

Micro vortex flows induced by thermoplasmonic Marangoni effect

Kyoko Namura, Kaoru Nakajima, Kenji Kimura, Motofumi Suzuki, Kyoto Univ. (Japan)

Marangoni flow, which is induced by temperature gradient along a gas-liquid surface, has attracted much attention in the field of microfluidics. A challenge in controlling the Marangoni flow in micro channels is to generate a steep temperature gradient at a desired position. Recently, we reported highly localized thermoplasmonic effect of gold nanoparticles array/dielectric/silver mirror multilayered thin films due to strong interference [1]. A focused laser spot on these films can be used as a mobile point heat source. Here we investigate Marangoni flows induced by thermoplasmonic effect of the thin film in micro channels.

We fabricated the thin films with gold nanoparticles array by using the dynamic oblique deposition technique [1]. On the film, shallow cells with various heights were prepared. Each cell was filled with water in which polystyrene spheres were dispersed in order to visualize the flow. Then, the microfluidic control was performed under laser illumination (wavelength: 785 nm).

In the microfluidic cell, a micro bubble was created by focusing the laser onto the film. Around the micro bubble, two symmetric rapid micro vortex flows developed. The local flow velocity exceeded 10 mm/s even in the cell with 50 ?m height. This result suggests that the highly localized thermoplasmonic effect of the gold nanoparticles induces steep temperature gradient along the bubble surface and subsequently causes the rapid vortex flow, which is useful for mixing, collecting, and sorting particles dispersed in a fluid.

[1] K. Namura, et al., Appl. Phys. Lett. 106, 043101 (2015).

9668-9, Session 1B

Carbon nanohorn and carbon nanotube nanofluids for solar thermal collectors

Sara Mesgari Hagh, Natasha E. Hjerrild, Rory Clifford, Felipe Crisostomo, Robert A. Taylor, The Univ. of New South Wales (Australia)

Carbon nanofluids are engineered materials with controllable thermal and optical properties. For solar thermal applications, they are uniquely well-suited due to their high spectral absorptivity over the entire solar range. Among carbon nanomaterials, carbon nanotubes (CNTs) have attracted particular attention as a potentially new class of solar thermal absorbers. The application of CNTs as solar thermal absorbers is, however, currently hindered by the difficulties in achieving CNT dispersions which remain stable at elevated temperatures. In addition, typical solvents used for CNT dispersions are mostly not suitable for solar thermal applications due to their relatively low boiling points. One approach to achieving more stable carbon nanofluids for solar thermal applications is to use carbon nanomaterials with weaker inter-particle interactions including carbon nanohorns (CNHs) while offering a similarly high solar absorption, due to their weaker inter-particle interaction and horn-like shape tend to disperse better than CNTs at normal temperatures. However, the stability of CNHs nanofluids at elevated temperatures experienced in solar thermal applications has not been investigated. By analysing the results of a comprehensive series of experiments, this paper compares the thermal stability of CNHs and CNTs nanofluids at elevated temperatures of up to 250 °C. CNTs and CNHs were chemically functionalized to obtain stable dispersions in water, Glycerol and Therminol (synthetic non-polar oil). The stability of chemically functionalized CNHs and CNTs dispersions at different temperatures including 80, 150, 200 and 250 °C was investigated. The identified stable nanofluids may open a new class of nanofluids for use as solar thermal absorbers.

9668-10, Session 1B

Investigation of convective heat transfer in microchannels with superhydrophobic surfaces and nanofluids

Chia-Yang Chung, Robert A. Taylor, Majid E. Warkiani, The Univ. of New South Wales (Australia); Gary Rosengarten, RMIT Univ. (Australia)

Both microchannels and nanofluids have shown promise to enhance convective heat transfer. However, the major drawback of these two technologies is their significant increase of pumping pressure due to increased frictional drag (for microchannels) or increased fluid viscosity (for nanofluids). It is possible to decrease frictional drag, and overcome this drawback (to some extend), by implementing superhydrophobic surfaces to create slip with the channel wall. In this project, precise control of surface microstructures and surface chemistry is used to create superhydrophobic surfaces which are capable of reducing the frictional drag in channel flow and thus, reduce the pumping pressure. While there has been extensive research on fluid dynamic aspects of superhydrophobic surfaces, little research has investigated how they alter thermal transport of liquid flow. Further, the interaction between different superhydrophobic microstructures and nanoparticles-based suspension not yet been studied at all with respect to convective heat transfer. In this study, initial results of experiments of how three different superhydrophobic microstructures transport heat to a variety of nanofluid formulations will be presented. Detailed measurements of pressure drops and heat transfer coefficients are compared with existing theoretical equations and computation fluid dynamics simulations. We will show that superhydrophobic surfaces may be used to minimise heat losses while improving mass transport of nanofluids in microchannel heat exchangers (by up to 15-20%).

9668-11, Session 1C

Functional photonic nanostructures based on resonant dielectric nanoparticles *(Invited Paper)*

Isabelle Staude, Friedrich-Schiller-Univ. Jena (Germany) and The Australian National Univ. (Australia); Manuel Decker, Katie E. Chong, Dragomir N. Neshev, The Australian National Univ. (Australia); Igal Brener, Sandia National Labs. (United States); Yuri S. Kivshar, The Australian National Univ. (Australia)

Driven by their potential to provide a low-loss alternative for functional plasmonic nanostructures, the study of high-permittivity all-dielectric nanoparticles has emerged recently as a new branch of nanophotonics. Such dielectric nanoparticles support localized Mie-type resonances, whose properties can be tailored via the size, shape, material composition and arrangement of the nanoparticles [1,2]. In addition, the controlled superposition of two or more resonances with different multipolar characteristics offers a versatile route for shaping the far-field scattering patterns of the nanoparticles [1,2].

In this talk, we review this new emerging field of all-dielectric nanophotonics, and we demonstrate that the Mie-type resonances in dielectric nanoparticles and subwavelength-patterned dielectric structures can be exploited to boost the performance of many photonic devices such as wavefront-shaping metasurfaces and optical nanoantennas. We will discuss how the magnetic and electric dipolar resonances of a silicon nanoparticle can be tailored to exhibit electromagnetically dual-symmetric optical properties, and we will demonstrate that such nanoparticles can be used as the building blocks of resonant metasurfaces for wavefront engineering with near-unity transmittance efficiency. We will then focus on the higher order multipolar resonances of dielectric nanoparticles, discuss their potential for spontaneous emission enhancement, and show how they can be exploited to generate highly directional scattering patterns. Finally, we will touch on nonlinear effects driven by magnetic response in dielectric nanoparticles and on coupling effects observed in small ensembles of nanoparticles.

[1] I. Staude et al., ACS Nano 7, 7824 (2013).

[2] M. Decker et al., Adv. Opt. Mater., DOI: 10.1002/adom.201400584 (2015).

9668-12, Session 1C

Fabrication and optical characterisation of InGaN/GaN nanorods

Xi Dai, The Univ. of New South Wales (Australia) and Max-Planck-Institut für die Physik des Lichts (Germany); Xiaoming Wen, The Univ. of New South Wales (Australia); Michael Latzel, Max-Planck-Institut für die Physik des Lichts (Germany) and Friedrich-Alexander-Univ. Erlangen-Nürnberg (Germany); Martin Heilmann, Max-Planck-Institut für die Physik des Lichts (Germany); Christian Appelt, Max-Planck-Institut für die Physik des Lichts (Germany) and Helmholtz-Zentrum Berlin für Materialien und Energie GmbH

(Germany); Yu Feng, Jianfeng Yang, Weijian Chen, Shujuan Huang, Santosh Shrestha, The Univ. of New South Wales (Australia); Silke H. Christiansen, Max-Planck-Institut für die Physik des Lichts (Germany) and Helmholtz-Zentrum Berlin für Materialien und Energie GmbH (Germany); Gavin Conibeer, The Univ. of New South Wales (Australia)

We report the fabrication and various nanoscale fluorescence mappings of the InGaN/GaN nanorod arrays. The advanced characterisations used in this work provide unique insight into carrier dynamics in the nanoscale region. Nanosphere lithography and reactive ion etching techniques are adopted to fabricate densely packed nanorod arrays with controllable diameter and high hexagonal periodicity. The nanorods exhibit greatly enhanced luminescence compared to the initial planar sample. We demonstrate, to the best of our knowledge, for the first time, the use of selective wavelength two-photon fluorescence mapping with an excitation depth profile combined fluorescence lifetime imaging (FLIM) to study the carrier dynamics of the InGaN/GaN nanorods. Carriers are excited to the GaN band edge (free excitons) and the GaN sub-bandgap deep states (bound excitons) to investigate the depth-resolved carrier transport and recombination under two-photon excitation. FLIM extended laser confocal microscope monitors the significant changes in carrier lifetime after nanofabrication. Both cathodoluminescence mapping and photoluminescence excitation measurements are in good agreement with the results of two-photon fluorescence mapping, indicating that two-photon fluorescence is a promising technique to study the depth-resolved carrier dynamics of the nanorods. This work is most crucial to understand the optical properties with respect to the depth-resolved carrier transport and recombination in InGaN/GaN nanorods for the optimisation of related device efficiency.

9668-13, Session 1C

Photonics of two-dimensional materials beyond graphene

Qiaoliang Bao, Monash Univ. (Australia) and Soochow Univ. (China); Yupeng Zhang, Monash Univ. (Australia); Yunzhou Xue, Monash Univ. (Australia) and Soochow Univ. (China); Shaojuan Li, Soochow Univ. (China)

The success in graphene with fascinating and technologically useful properties[1] has stimulated the study of two-dimensional (2D) atomic-layer materials other than graphene, such as single layers of transition metal dichalcogenides (TMDCs, e.g., MoS2, WS2, WSe2, etc)[2] and a few quintuple layers of topological insulators (TIs, e.g., Bi2Se3, Bi2Te3, Sb2Te3 etc)[3]. The rapid pace of progress in graphene, TMDCs and TIs and some demonstrated applications have led to the exploration of new type of electric and optoelectronic devices constructed by vertically stacking different layered materials. [4-9]

Here we would like to review our recent progresses on the photonic applications of 2D layered materials other than graphene. A few photonics devices based on these 2D materials or their heterostructures have been successfully fabricated, including pulse laser, photodetector, solar cell, modulator and ring filter. Firstly, we use graphene as template to grow graphene/topological insulator heterostructure and investigate the linear and nonlinear optical properties as well as the application for pulse laser generation.[4] Broadband photodetection was also demonstrated on this heterostructure. [5] Ultrahigh responsivity and gain was proved in hybrid graphene-perovskite phototransistors.[6] Secondly, we develop new approach to grow and transfer large area TMDCs,[7-8] which is the basis for fabrication of new type of flexible thin film photodetectors and solar cell devices. Last, based on the good CMOS-compatibility of 2D materials [9], we fabricate chip-integrated modulator and resonator devices and incorporate graphene/TMDCs heterostructure for the signal modulation and processing. The advances of photonics of these new 2D materials may pave the way for the integration of next generation hybrid silicon photonic circuit

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[9] Sheng Gan, et al., Advanced Optical Materials, 2015, submitted.

9668-14, Session 1C

Low loss and single mode hybrid-clad waveguides for Terahertz radiation

Haisu Li, The Univ. of Australia (Australia); Shaghik Atakaramians, Boris T. Kuhlmey, The Univ. of Sydney (Australia)

Several waveguide solutions based on technologies from both electronics and photonics have been proposed for guiding Terahertz (THz) radiation [Adv. Opt. Photonics 5, 169 (2013)]. Hollow-core dielectric waveguides are one of the best options for guiding THz radiation since the material ab-sorption is almost zero in the air-core. However, these waveguides are usually multimode and have dimensions in the order of a few millimeters. Here we propose a hollow-core waveguide with sub-wavelength scale metallic wires in the cladding for THz guidance. The theoretical studies show that the hybrid cladding reflects the transverse magnetic (TM) waves and transmits the transverse elec-tric (TE) waves, leading into a waveguide structure that only confines TM modes. The numerical simulations show a single mode operation window from 0.22 THz to 0.34 THz and 11.7 dB/m prop-agation loss at 0.29 THz. Compared to a metallic waveguide with similar dimension, the proposed waveguide has more than double single mode operating region with comparable losses. The effect of optical and structural parameters of hybrid cladding on the single mode operating window and prop-agation losses will be discussed in detail. Moreover, details of the fabrication of the proposed wave-guide will be introduced. Furthermore, the design principle of proposed waveguide can be extended to mid-inferred.

9668-15, Session 1C

Mid-IR silicon pillar waveguides

Neetesh Singh, Darren D. Hudson, Benjamin J. Eggleton, The Univ. of Sydney (Australia)

The extension of CMOS compatible photonic integrated circuit into the mid-infrared (mid-IR) is limited due to the substrate absorption losses . Here we propose an approach where the optical modes are guided almost independently of the substrate. We designed geometries (inverted L and upright T), which can guide light along the waveguide away from the substrate over the entire mid-IR region.

These structures support 4 ZDWs and have a flat dispersion over a wide mid-IR range, 2-6 μm, which is useful for low power operation and exploiting nonlinear phenomenon such as a supercontinuum generation. The waveguides were dispersion engineered by calculating the effective index, neff (with FEM in COMSOL), using the sellmeier equation for bulk silicon and sapphire. The dispersion is calculated with, D = - (c/?)d2neff /d?2.

Dispersion of the T waveguides varies by (+-)25 ps/nm-km in the range 2.2-5 μm, whereas, for the L waveguide the dispersion varies by (+-)29 ps/nm-km from 2.1-6.2 μm. The mode confinement for both of the structures is high in the mid-IR. For example, the mode cut-off for the T waveguide is around 7.15 μm, whereas, the L waveguide confines light beyond silicon absorption edge (the mode confinement in silicon ~ 40%, sapphire ~ 36% and air ~ 24% at 8.6 μm)

The calculated supercontinuum extends over 2-8 μm for pumping in anomalous region close to 3rd ZDW. Hence, these waveguides have potential applications in mid-IR sensing, nonlinear studies as well as a broad band light source operating over the entire silicon transparency.

9668-2, Session 2A

All-dielectric Huygens' metasurfaces of different symmetries

Sergey S. Kruk, The Australian National Univ. (Australia); Ivan I. Kravchenko, Oak Ridge National Lab. (United States); Yuri S. Kivshar, The Australian National Univ. (Australia)

The study of optical metasurfaces have become an active research direction in the field of metamaterials for creating a new generation of flat optical metadevices with superior functionalities and small sizes. Being typically an order of magnitude thinner than the wavelength of light, metasurfaces allow to control the phase of propagating light waves across the full 2ϖ range and therefore they enable the realization of optical elements such as lenses, waveplates, and beam converters. Recently suggested Huygens' metasurfaces are highly efficient all-dielectric planar structures employing the concept of a Huygens' source realized by a lattice of nanoscale elements, each being designed in such a way that it supports spectrally overlapping optically-induced electric and magnetic dipole resonances of equal strength, resulting in the overall near-unity transmission of a metasurface. Here we suggest, fabricate, and study experimentally several types of Huygens' metasurfaces with different symmetries. We fabricate seven types of metasurfaces composed of meta-atoms in the form of nanodisks or nanorings supporting both electric and magnetic dipole resonances, and we arrange them into lattices of three different symmetries, namely square, hexagonal, and quasi-periodic lattices (in the latter, nanodisks are placed on the vertices of a Penrose tiling). Our results demonstrate almost perfect transmission reaching unity and precisely controlled phase delay covering the full 2ϖ range. We study the optical response of the Huygens' metasurfaces with different symmetries for the scenarios of oblique illumination and non-collimated beams and test the feasibility of engineering functional optical element, such as high-aperture lenses, using this approach.

9668-16, Session 2A

Polarisation and phase sensitive metasurfaces for imaging and information processing *(Invited Paper)*

Ann Roberts, Jasper J. Cadusch, Evgeniy Panchenko, Timothy D. James, The Univ. of Melbourne (Australia); Kevin J. Webb, Purdue Univ. (United States); Daniel E. Gómez, Commonwealth Scientific and Industrial Research Organisation (Australia); Tim Davis, The Univ. of Melbourne (Australia)

Polarisation and phase are a key properties of lightfields that can be utilised in applications including from information processing, optical communications and imaging. Nanoscale, plasmonic elements can be tailored to have a characteristic response to these properties providing an avenue for the development of ultracompact devices that, in conjunction with scalable fabrication processes, will support the realisation of new applications and commercial development. Here theoretical and computational progress toward the design and demonstration of novel, ultrathin metasurfaces will be presented.

9668-17, Session 2A

Colloidal metamaterials

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We propose a new type of metamaterial, a meta liquid crystal, which is made of thin elongated dielectric particles hosting chains of anisotropic metallic meta-atoms, and these particles are dispersed in a liquid environment. These elements reorient in response to static electric field, directing the axis of anisotropy, thus tuning the electromagnetic response of the whole structure. In comparison to other metamaterials, this is a truly three-dimensional metamaterial in a liquid phase that can occupy arbitrarily shaped volumes. There is considerable freedom to design the electromagnetic properties through the appropriate choice of the meta-atom geometry, and the electrodynamic and electrostatic responses can differ greatly. We fabricate such tunable meta liquid crystals and demonstrate that they can modulate both the amplitude and phase of transmitted terahertz signals. We find that significant modulation contrast and linear birefringence can be achieved even for very small volume densities. We study three different designs and compare their performance. Our study demonstrates the feasibility of meta liquid crystals as a novel form of three dimensional tunable metamaterial.

9668-18, Session 2A

Mesoscopic effects in discretised metamaterial spheres

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We consider a series of metamaterial samples having a cubic lattice, truncated to a shape as close to a sphere (being the most canonical 3D object) as possible for a given size. Clearly, for small spheres with just a few unit cells along the diameter the shape is remarkably ragged, however larger spheres appear reasonably smooth overall. For such a finite system under a given excitation, the induced currents and hence the magnetisation can be calculated directly taking all the mutual interactions between the loops into account. We have observed that the calculated magnetisation curves for small discrete samples show remarkable deviations and less trivial frequency dependence, however the convergence towards the continuous model improves with size and becomes a clear trend for sizes above 13-14, and the results for the spheres of 15 and larger appear very similar to each other; initially "ragged" configuration shows somewhat better convergence compared to a "flat" one. Even so, there is still a difference between large discrete spheres and the continuous one, which may be attributed to the effect of the elements closest to the boundary, which do not form a perfect spherical surface but a corrugated one, with the spherical approximation becoming increasingly good with size. While we have no computational tools to calculate much larger samples, we hypothesise that eventually the difference between a discrete sphere and a continuous one can be eliminated to good precision. Our observations may have severe implications for practical design and future development of metamaterials.

9668-19, Session 2A

Nanostructuring for enhanced light absorption

Ali Mirzaei, Ilya V. Shadrivov, Andrey E. Miroshnichenko, Yuri S. Kivshar, The Australian National Univ. (Australia)

We suggest a new technique, to enhance and improve the absorption of light by multilayer nanostructures made of dielectric and plasmonic materials.. This strategy makes the total absorbed energy substantially larger than that achieved in homogeneous nanowires. We use the multipole expansion method and experimental data for material parameters to analyze multilayer nanowires. In solid metallic nanowires the absorption is considerable only close to the plasmonic resonance frequency and negligible elsewhere. In solid dielectric nanowires, several resonances exist, but they are well spaced in the frequency domain, so that the overlapping between them is not substantial. To overcome these restrictions of enhancing the absorption, in this work we introduce a multi-mode absorption approach, aiming at a design of structures that have several resonances co-existing at a selected frequency. To achieve this, we engineer multilayer nanowires by employing a smart genetic algorithm to overlap different resonant modes in a certain wavelength and demonstrate that the absorption can be enhanced far beyond the single-mode limit. We show that

our approach can be employed for a design of multiband tunable optical absorption across a wide spectral range for both TE and TM polarizations using either plasmonic materials or all-dielectric structures.

9668-20, Session 2A

Artificial electrostriction in metamaterials

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Photoelasticity (the change in permittivity of a dielectric subject to mechanical strain) and its reverse process electrostriction (the strain induced by an electric field intensity) constitute one of the two interaction mechanisms that govern the fields of opto-mechanics and Stimulated Brillouin Scattering (SBS). These two fields have recently gained considerable attention both in fundamental and applied physics. To date, surprisingly little attention has been devoted to the possibility of tailoring the photoelastic coupling by the use of metamaterials, although metamaterials are well-known for exhibiting a wide range of optical effects with unusual magnitude (e.g. ultra-strong dichroism) or of unusual nature (e.g. negative refraction).

Here, we report on our latest theoretical investigations of artificial photoelasticity and SBS enhancement in 3d metamaterials. In this, we derive analytical expressions for the scalar photoelastic constant via a combination of the Maxwell-Garnett theory of dilute composite materials and thermodynamic principles. This explicit result sheds light on how the complex interplay between the mechanical and dielectric properties of the constituent materials results in a macroscopic effective photoelasticity. We demonstrate photoelastic enhancement factors of orders of magnitude for resonant plasmonic metamaterials (lossy) and factors in excess of three for purely dielectric (lossless) systems. Our analysis demonstrates that metamaterials can be tailored to exhibit strongly positive, strongly negative and vanishing photoelasticity.

9668-21, Session 2A

Dynamic control of THz waves through thin-film transistor metamaterials

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Recently, the THz technology has attracted much attention for its potential applications from medical to manufacturing sectors. In the search for materials to overcome the accessibility difficulties in THz gap, a class of composite artificial materials termed electromagnetic metamaterials has emerged. Given that the resonant unit cell can be controlled by external stimulus, the modulation of THz radiation is thus allowed. So far, various ways to accomplish metamaterial modulators for THz radiation have been demonstrated based on Si, GaAs, or graphene. However, they are unsuitable for large area fabrication, and actually pose more stringent requirement on simple fabrication process. In this work, we demonstrated an active metamaterial with embedded thin film transistors (TFTs) made of ionic amorphous oxide semiconductors. The properties of hybrid metamaterial system are theoretically investigated via the commercially available CST Microwave Studio software. At zero gate bias, the metamaterial shows a significant electric resonance around 0.75 THz. By sweeping the gate bias from 0 to 24 V, the capacitive split gap is gradually shortened due to the conductivity of oxide layer increases up to 40 S/m. At 24 V, a 5 dB relative intensity change of transmissivity and only a small frequency red-shift of about 15 GHz are observed. Despite of the large device area, it has a cut-off frequency of ~1 kHz. Such transparent TFTs based controllable metamaterials are of energy saving, low cost and ready for mass-production, which are expected to be widely used in future terahertz imaging, sensing, communications and others.

9668-23, Session 2A

Perfect Terahertz absorber through resonance impedance matching of all dielectric cylinders

Michael Cole, David A. Powell, Ilya V. Shadrivov, The Australian National Univ. (Australia)

Metamaterials offer flexibility in the design of the frequency-selective electromagnetic wave absorbers for imaging and detection applications. Most absorbers are based on metallic resonant elements or on highly absorbing non-resonant dielectric materials. Here we propose a metamaterial absorber based on dielectric cylinders of finite length. Such cylinders possess both electric and magnetic resonances, whose frequencies can be moved with respect to each other by changing the ratio of the cylinder height to its diameter. An appropriate choice of the mutual position of electric and magnetic resonances allows impedance matching of the array of such resonators with free space, thus eliminating reflection. Based on this mechanism we theoretically demonstrate the possibility of the near-perfect absorption at multiple frequencies. For particular calculations, we choose the terahertz frequency range, where frequency-selective absorption is of particular interest. A unit cell of our metamaterial structure consists of a dielectric cylinder embedded in a low-index material. The impedance matching is achieved by varying the aspect ratio, height vs. diameter, of our all dielectric cylinders. We show that we can achieve absorption of at least 99.5% at multiple frequencies between 0.3 and 1.7 THz by scaling the diameter of our cylinders while maintaining a nearly constant aspect ratio. The design is quite sensitive to material choice for the cylinders, and we found that it is appropriate to use materials with a real dielectric permittivity of approximately 7.5 with a loss tangent of 0.03, which will serve as a starting point for choosing materials for real absorber designs.

9668-24, Session 2A

Optical properties of InAs/GaInSb superlattices

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A periodic structure of semiconductor superlattice (SL) with nanometer-scale layers of InAs and GaInSb creates a series of quasi-2D electron subbands that are different from the energy band structure in the bulk materials. By changing the thickness of the layers and the In content in GaInSb the designed energy gaps and the optical properties of the SL can be engineered for a particular spectrum range from the near-infrared to terahertz (THz). This presentation reports on optical properties of InAs/GaInSb superlattices, which were designed for long-wavelength, terahertz detectors (SL bandgap <50 meV). The samples were grown by solid-source Molecular Beam Epitaxy on GaSb (100) substrates. The SL subband structure and the dielectric properties are evaluated from the transmittance and reflectance spectra measured by FTIR and THz time-domain spectroscopy. The characteristics are compared with the theoretical calculations using the eight-band k?p method and the simulated dielectric functions based on the Drude-Lorentz oscillator model.

9668-25, Session 2A

Photophysics of point defects in zinc oxide nanoparticles

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Zinc oxide (ZnO) nanoparticles have recently been identified as a promising candidate for advanced nanophotonics applications and quantum technologies. One of the most fascinating applications of ZnO is its ability to host bright fluorescent defects that exhibit luminescence across the entire visible range, facilitating extensive applications in

lighting technologies. In this work, we perform comprehensive studies on the formation and photophysical properties of point defects in ZnO nanoparticles. Various annealing treatments were applied to generate the defects within the ZnO nanoparticles. We employ correlative characterization techniques to assign optical emission peaks and electron paramagnetic resonance (EPR) lines to specific defects in ZnO nanoparticles. The deep-level cathodoluminescence (CL) emission of the as-received ZnO nanoparticles exhibits a broad visible band centered at 1.82 eV. Annealing in oxygen atmosphere induces strong green luminescence at 2.28 eV, while zinc vapor annealing produces a green peak centered at 2.48 eV. It is shown using correlative photoluminescence, CL, EPR and x-ray absorption near edge spectroscopy that an optical emission peak at 2.28 eV has been attributed to a zinc vacancy related center while an emission at 2.48 eV and corresponding EPR signal at g = 2.00 has been assigned to surface oxygen vacancy centers. These radiative point defects can be excited using both above bandgap and sub-bandgap excitation which is beneficial for devices and different centers exhibit lifetimes ranging from nanoseconds to microseconds. These exciting luminescence properties of ZnO nanostructures are important to the future development of ZnO materials for nanophotonics, optoelectronics and quantum applications.

9668-26, Session 2A

Perovskite-based photodetectors: fabrication and optimisation

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Recently, a group of organic/inorganic hybrid perovskite materials have been reported with rapid progress in high performance photovoltaic device such as solar cells and photodetectors [1]. The long charge carrier lifetime and diffusion length, low recombination of charge carriers, high external quantum efficiency, and a very low density of defects and traps within the bandgap strongly indicate that the hybrid perovskite materials are ideal candidates for photodetector applications [2].

Given the above-mentioned advantages of the material's properties, we demonstrate three types of perovskite based photodetectors: 1) The first one was a hybrid photodetector that consisted of monolayer graphene covered with a thin layer of dispersive CH3NH3PbBr2I grains. The device exhibited extremely high responsivity (6.0?105 AW-1) and high photoconductive gain (109) because of effective photo-gating effect applied on graphene and increased lifetime of trapped photocarriers in separate perovskite nanocrystals, which were visualized by scanning near-field optical microscopy technique for the first time [3]. 2) The second one was fabricated using hybrid CH3NH3PbI3-graphene composite. Interface engineering of perovskite by graphene could relieve the potential barrier created by trapped carriers at the boundaries, increase the mobility of free carriers, and reduce the local resistivity, which has been verified by photocurrent mapping [4]. 3) The third one was a flexible photodetector fabricated by using oriented mesoporous Fe2O3 and perovskite heterostructures. The oriented mesoporous nanopyramid arrays Fe2O3 as electron transporting materials not only exhibit large surface area, but also rapid charge transport and reduced recombination, which are credited with remarkable enhancement of photoresponsivity [5].

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9668-27, Session 2A

Humidity sensing using resonance-enhanced absorption in dye-doped polymer thin-film on metal substrates

Madhuri Kumari, Boyang Ding, Richard J. Blaikie, Univ. of Otago (New Zealand)

We demonstrate novel humidity sensors based on optical resonances in sub-wavelength thick dye-doped polymer coatings on reflecting surfaces. The reflection spectra of such thin-film cavities show strong resonant features as a result of coupling between dye molecular absorption and novel absorbance-modified interference resonances [1,2]. These resonances are extremely sensitive to environmental conditions, such as the thickness of the coatings and the concentration of dye, which makes the thin-film system an excellent candidate for gas and chemical sensing.

As a proof of principle, we present one application of the system in humidity sensing. Specifically, the sample consists of an 80-nm thick Rhodamine6G doped (17.5 mM) polyvinyl alcohol (PVA) film on a silver substrate. We monitor the reflection spectrum of the sample for different values of relative humidity (RH). The s-polarised reflection spectrum under nearly normal incidence (5) shows a minimum at 527 nm at RH = 44%, which blue-shifts to 499 nm as the RH increases to 66%. Numerical simulations, which match experimental results well, demonstrate that the observed shift of the reflection minimum arise from the changes in the thickness of PVA coating as it absorbs water. In addition, the RH sensitivity can be significantly enhanced by exciting the resonances in a 95 nm thick PVA film (doped with 0.5 mM Rhodamine6G) on silver substrate. In this case, at highly oblique incidence (81) the reflection minimum red-shifts by 101 nm for the same changes in RH, an increase in sensitivity by a factor of 3.6 as compared with the previous case.

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9668-29, Session 2B

Enhanced water vapour flow in silica microtubes explained by Maxwell's tangential momentum accommodation and Langmuir's adsorption

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Maxwell introduced the tangential momentum accommodation coefficient (TMAC) in 1879 to describe boundary conditions in fluid flow. Recent findings of anomalously high gas flow rates in carbon nanotubes show how smooth hydrophobic walls can increase specular reflection of molecules and reduce TMAC. Here we report the first measurements of water vapour flows in microtubes over a wide humidity range and show that for hydrophobic silica there is a range of humidity over which an adsorbed water layer reduces TMAC and accelerates flow. Our results show that this association between hydrophobicity and accelerated moisture flow occurs in readily available materials. We develop a hierarchical theory that unifies Maxwell's ideas on TMAC with Langmuir's ideas on adsorption. We fit the TMAC data as a function of humidity with the hierarchical theory based on two stages of Langmuir adsorption and derive total adsorption isotherms for water on hydrophobic silica that agree with direct observations. We propose structures for each stage of the water adsorption, the first reducing TMAC by a passivation of adsorptive patches and a smoothing of the surface, the second resembling bulk water with large TMAC. We find that leak testing of moisture barriers with an ideal gas such as helium may not be accurate enough for critical applications and that direct measurements of the water leak rate should be made.

9668-30, Session 2B

Low-temperature bonded glass-membrane microfluidic device for in vitro organ-on-a-chip cell culture models

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The integration of microfluidics with living biological systems has paved the way to the exciting concept of "organs-on-a-chip", which aims at the development of advanced in vitro models that replicate the key features of human organs [1]. Glass based devices have long been utilised in the field of microfluidics but the integration of alternative functional elements within multi-layered glass microdevices, such as membranes, remains a challenge.

To this end, we have extended a previously reported approach for the low-temperature bonding of glass devices [2]. Towards the development of organs-on-chip microfluidic technology, a low-temperature bonding technique has been successfully used to fabricate microdevices comprising of two glass substrates separated by a thin poly carbonate (PC) membrane. The technique was initially developed and optimised on specialty low-temperature bonding equipment (?TAS2001, Bondtech, Japan) and subsequently adapted to more widely accessible hot embosser units (EVG520HE Hot Embosser, EVG, Austria). The key aspect of this method is to use low temperatures, compared to borosilicate glass bonding (650 oC) [3] and quartz/fused silica bonding (1050 oC) [4], to maintain the integrity of the delicate membrane (Tg 150 oC). Incorporating the thin (15 µm) membrane is paramount as physical separation is one of the major factors controlling the differentiation process of co-cultured cells in organ-on-a-chip models. Leak tests performed using a Fluorescein dye showed no difference after 150 hours indicating sufficient bond strength for long term cell culture. With potential applications such as culturing dense layers of Caco-2 cells inside the microchannel. The low-temperature bonding technique itself along with direct application to an intestine-on-a-chip in vitro model will be presented.

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9668-31, Session 2B

Printed circuit boards as platform for disposable lab-on-a-chip applications

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An increasing demand in performance from electronic devices has resulted in continuous shrinking of electronic components. This shrinkage has demanded that the primary integration platform, the printed circuit board (PCB), follow this same trend. Today PCB companies offer ~100 micron sized features which mean they are becoming suitable as platforms for Lab-on-a-Chip and microfluidic applications. Compared to current lithographic based fluidic approaches; PCB technology offers several advantages that are useful for this technology. These include: Being easily designed and changed using free software, robust structures that can often be reused, and chip layouts that can be ordered from commercial PCB suppliers at very low cost. Here we present the application of PCB technology in connection with microfluidics for several potential biomedical applications such as cell/particle separation based on dielectrophoresis and the detection of protease activity in a miniaturized electrophoretic assay with microarray like fluorescence read-out. Each device is around 1 dollar in cost at the moment and does not require any post-processing. In contrast to conventional microfluidics, electrodes for electrical manipulation or read-out are already integrated using this technology. In case of commercialization the costs for each device can be even further decreased to approximately one tenth of its current cost.

9668-32, Session 2B

Enabling rapid behavioral ecotoxicity studies using an integrated lab-on-a-chip systems

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Behavioral ecotoxicity tests are gaining an increasing recognition in environmental toxicology. Behavior of sensitive bioindicator species can change rapidly in response to an acute exposure to contaminants and thus has a much higher sensitivity as compared to conventional LC50 mortality tests. Furthermore, behavioral endpoints seems to be very good candidates to develop early-warning biomonitoring systems needed for rapid chemical risk assessment. Behavioral tests are non-invasive, fast, do not harm indicator organisms (behavioral changes are very rapid) and are thus fully compatible with 3R (Replacement – Reduction – Refinement) principle encouraging alternatives to conventional animal testing. These characteristics are essential when designing improved ecotoxicity tests for chemical risk assessment. In this work, we present development of two miniaturized Lab-on-a-Chip (LOC) platform technologies that enable in depth studies of toxin avoidance behaviors of a freshwater crustacean Daphnia magna (Daphtoxkit-FTM) and a marine shrimp Artemia franciscana (Artoxkit M™). As an investigative tool, LOCs represent a new direction that may miniaturize and revolutionize behavioral ecotoxicology research. Specifically our innovative microfluidic devices: (i) enable convening "caging" of specimens for real-time videomicroscopy; (ii) eliminate the evaporative water loss thus providing an opportunity for long-term behavioral studies; (iii) exploit laminar fluid flow under low Reynolds numbers to generate discrete domains and gradients enabling for the first time toxin avoidance studies on small aquatic crustaceans; (iv) integrate off-the-chip mechatronic interfaces and video analysis algorithms for single animal movement analysis. We provide evidence that by merging innovative bioelectronic and biomicrofluidic technologies we can deploy inexpensive and reliable systems for culture, electronic tracking and complex computational analysis of behavior of bioindicator organisms.

9668-33, Session 2B

3D printed polymers toxicity profiling: a caution for biodevice applications

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A recent revolution in additive manufacturing technologies and access to 3D Computer Assisted Design (CAD) software has spurred an explosive growth of new technologies in biomedical engineering. This includes biomodels for diagnosis, surgical training, hard and soft tissue replacement, biodevices and tissue engineering.. Moreover, recent developments in high-definition additive manufacturing systems such as Multi-Jet Modeling (MJM) and Stereolithography (SLA), capable of reproducing feature sizes less than 100 µm, promise brand new capabilities in fabrication of optical-grade biomicrofluidic Lab-on-a-Chip and MEMS devices. Compared with other rapid prototyping technologies such as soft lithography and infrared laser micro-machining in PMMA, SLA and MJM systems can enable user-friendly production of prototypes, superior feature reproduction quality and

comparable levels of optical transparency. Prospectively they can revolutionize fabrication of microfluidic devices with complex geometric features and eliminate the need to use clean room environment and conventional microfabrication techniques. In this work we have performed a comprehensive toxicity profiling of a panel of common polymers used in 3D printing applications. The main motivation of our work was to evaluate toxicity profiles of most commonly used polymers using standardized biotests according to OECD guidelines for testing of chemicals . Our work for the first time provides an in-depth and multispecies view of potential dangers and limitation for building biocompatible devices using FDM, SLA and MJM additive manufacturing systems. Our work shows that additive manufacturing holds significant promise for fabricating LOC and MEMS but requires caution when selecting systems and polymers due to significant toxicity exhibited by a vast majority of SLA and MJM polymers.

9668-34, Session 2B

Lab-on-chip platform for circulating tumor cells isolation

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We designed, developed and demonstrated the principle of a continuous, non-intrusive, and low power microfluidics-based lab-on-a-chip (LOC) structure for Circulating Tumor Cell (CTC) separation. Cell separation is achieved through 80 cascaded contraction and expansion microchannels of widths 60 µm and 300 µm, respectively, and depth 60 µm, which enable momentum-change-induced inertial forces to be exerted on the cells, thus routing them to desired destinations. The total length of the developed LOC is 72 mm.

The LOC structure is simulated using the COMSOL multiphysics software, which enables the optimisation of the dimensions of the various components of the LOC structure, namely the three inlets, three filters, three contraction and expansion microchannel segments and five outlets. Simulation results show that the LOC can isolate CTCs of sizes ranging from 15 to 30 µm with a recovery rate in excess of 90%.

Fluorescent microparticles of two different sizes (5 µm and 15 µm), emulating blood and CTC cells, respectively, are used to demonstrate the principle of the developed LOC. A mixture of these microparticles is injected into the primary LOC inlet via an electronically-controlled syringe pump, and the large-size particles are routed to the primary LOC outlet through the contraction and expansion microchannels.

Experimental results demonstrate the ability of the developed LOC to isolate particles by size exclusion with an accuracy of 80%. Ongoing research is focusing on the LOC design improvement for better separation efficiency and testing of biological samples for isolation of CTCs.

9668-35, Session 2B

Microfluidic device with integrated optical interfaces for miniaturized point-of-care blood analysis

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Fast and reliable blood analysis is vital for development of future point-of-care (POC) diagnostic systems. Despite of this importance, the utility of the current blood analysis systems is hampered by their size and weight.

In this paper, we demonstrate the implementation of a microfluidic-based chip for measuring the optical properties (absorption and scattering) of liquid samples as low as 220 µL. The light coupling into and out of the chip is realized with 45° total internal reflection mirrors. The chip and the mirrors are made of injection moulded transparent polymer (COC6013), and the channels are milled using a CNC milling machine. This provides a high flexibility, while maintaining a high precision. A syringe pump is used to enable liquid transport via magnetically attached tubing. An electronic readout comprising a nanosecond pulsed laser, small apertures and digital filtering enables measurements in ambient light. The whole setup and data acquisition is controlled via an automated computer program, and numerical signal processing is done in the post-processing.

Proof-of-concept experiments using Bentonite in deionized water show the possibility to quantify absorbency or turbidity of the sample by measuring transmitted and side scattered lights simultaneously, even in the presence of ambient light. The microfluidic system enables measuring the concentration of biomarkers within blood samples for future POC diagnostic systems.

9668-36, Session 2B

Bubble-induced acoustic mixing in a microfluidic device

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Homogeneous and fast mixing of small volume of samples is a critical requirement of biochemical analysis, chemical synthesis and nanomaterial synthesis etc. This paper reports the optimisation of a microfluidic mixer with defined air bubbles and piezoelectric (PZT) disks generating two dimensional resonance mode. The micromixer consists of a microwell (with the volume of 90 nL) with rectangular bubble traps around the well edge and two PZT disks (either round or rectangular) attached to the PDMS layer on the left hand and bottom side of the well. After the injection of liquid, air bubbles were reliably trapped in the rectangular traps around the well edge. When the excitation frequency of the PZT disk is equal to the resonance frequency of air bubbles, strong liquid recirculation (so called acoustic streaming) around the air bubbles was generated to mix the liquid. The acoustic streaming was characterised by micro Particle Imaging Velocimetry (µPIV), when a) the number and size of the bubbles, b) the shape and position of the PZT disk, c) the excitation frequency and d) the thickness of the PDMS layer varied. It is found that i) the bigger the bubble size, the better the mixing, ii) the rectangular PZT disks have much better mixing efficiency compared to the round PZT disks, iii) when the PZT is attached to the PDMS, the mixing effect is better than it is on the glass layer, and iv) when the PMDS is thinner, the mixing efficiency is dramatically increased. The optimised microfluidic mixer is reliable and repeatable and of great potential to be integrated with other lab on a chip devices.

9668-37, Session 2B

Automation of Daphtoxkit-F biotest using a microfluidic lab-on-a-chip technology

Yushi Huang, RMIT Univ. (Australia); Dayanthi Nugegoda, RMIT University (Australia); Donald Wlodkowic, RMIT Univ. (Australia)

An increased rigor in water quality monitoring is not only a legal requirement, but is also critical to ensure timely chemical hazard emergency responses and protection of human and animal health. Bioindication is a method that applies very sensitive living organisms to detect environmental changes using their natural responses. Although bioindicators do not deliver information on an exact type or the intensity of toxicants present in water samples, they do provide an overall snapshot and early-warning information about harmful and dangerous parameters. Despite its critical importance, the broad deployment of rapid whole-organism ecotoxicity tests is profoundly

limited by the lack of appropriate bio-compatible automation, integrated optoelectronic sensors, and the associated electronics and analysis algorithms. In this work, we present development of a miniaturized Lab-on-a-Chip (LOC) platform for automation and enhancement of acute ecotoxicity test based on a freshwater crustacean Daphnia magna (Daphtoxkit-FTM). Daphnids' immobilization in response to sudden changes in environment parameters is fast, unambiguous, and easy to record optically. We also for the first time demonstrate that enables studies of sub-lethal ecotoxic effects using behavioral responses of Daphnia magna as sentinels of water pollution. The system working principle incorporated a high definition (HD) time-resolved video data analysis to dynamically assess impact of the reference toxicant on swimming behavior of D. magna. Our system design combined: (i) innovative LOC flow-through device for on-chip "caging" of Daphnia sp.; (ii) automated mechatronic interface for LOC fluidic system actuation and HD video data acquisition; and (iii) video analysis algorithms for single animal movement analysis. The system will be tested out with regard to its applicability for rapid water toxicity testing.

9668-40, Session 2B

Photo-convective forces for micro- and nano-photonics *(Invited Paper)*

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No Abstract Available

9668-220, Session 2B

Induction of human iPSC-derived cardiomyocyte proliferation revealed by combinatorial screening in high density microbioreactor arrays *(Invited Paper)*

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Inducing cardiomyocyte proliferation in post-mitotic adult heart tissue is attracting significant attention as a therapeutic strategy to regenerate the heart after injury. Model animal screens have identified several candidate signalling pathways, however, it remains unclear as to what extent these pathways can be exploited, either individually or in combination, in the human system. The advent of human cardiac cells from directed differentiation of human pluripotent stem cells (hPSCs) now provides academe and industry alike with the ability to interrogate human cardiac biology in vitro, but it remains difficult with existing culture formats to simply and rapidly elucidate signalling pathway penetrance and interplay. To facilitate high-throughput combinatorial screening of candidate biologicals or factors driving relevant molecular pathways, we developed a high-density microbioreactor array (HDMA) – a microfluidic cell culture array containing 8100 culture chambers. We used HDMAs to combinatorially screen Wnt, Hedgehog, IGF and FGF pathway agonists to identify the most potent molecular inducers of human cardiomyocyte proliferation, in terms of cell cycle activity (marked by Ki67), and an increase in cardiomyocyte numbers compared to controls. The combination of human cardiomyocytes with the HDMA provides a versatile and rapid tool for stratifying combinations of factors for heart regeneration.

9668-28, Session 2C

Chip-based optical frequency combs *(Invited Paper)*

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Optical frequency combs are having and will have enormous impact on many areas of science and technology, including time and frequency metrology, precision measurement, telecommunications, and astronomy. I will describe our recent research on a novel type of frequency comb that is based on parametric nonlinear optical processes in silicon-based microresonators. The dynamical behavior of how combs are generated in such a system is complex and include phase transitions, mode locking and synchronization, and femtosecond pulse generation. Ultimately, such chip-based combs offer great promise for creating devices that are highly integrated and stable and can operate from the visible to mid-infrared regimes.

9668-41, Session 2C

Damage monitoring using fiber optic sensors and by analysing electro-mechanical admittance signatures obtained from piezo sensor

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Structures such as mechanical-blades, shafts and aero-wings have to be monitored regularly for variations in strains due to damage/load. The strain in the structures increases either due to increased load or due to damage incurred in the structures. This article thus focuses on load/crack monitoring of a fixed-fixed beam using multiple smart materials, like fiber optic sensors and piezo sensors. The two types of fiber optic sensors are used in this research are fiber optic polarimetric sensors (FOPS) and fiber Bragg grating (FBG). FOPS and FBG are used for global strain monitoring (in the entire specimen) and the local strain monitoring (at the center of the specimen only) respectively. At the centre of the specimen, piezoelectric wafer active sensor (PWAS) is also attached. PWAS analyses electro-mechanical admittance signature variations to assess the global loading/damage condition of the specimen. These multiple smart materials together are able to monitor whether the change in the strain is due to the presence of the damage or it is due to the change in the loading condition of the structures. In other word, these smart materials can truly perform the damage/load monitoring of the structures.

9668-42, Session 2C

Optimisation of nanostructured metallic optical filters and prevention of performance degradation due to oxidative stress and aging

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The realisation of photonic devices with feature sizes well-below typical optical wavelengths has opened up a range of applications from molecular sensing to colour filtering. The metal films used for plasmonics however often have reactive surfaces which are quick to oxidise. Many plasmonics therefore are fabricated from noble metals and in particular gold due to its extremely widespread use and ease of deposition. For standard silicon manufacturing processes, however, the use of such inert metals is not possible hence fabrication of these devices out of materials such as copper and silver which are subject to so-called aging effects again becomes necessary. In some recent studies (e.g. Kravets et al. Scientific Reports, 2014) graphene has been proposed as a suitable protection layer. Here we present the results of two experimental studies. In the first study presented here we demonstrate that diamond-like carbon can provide a simpler alternative means of protecting plasmonic devices without any degradation of performance. In the second study we present the results of a systematic experimental investigation into the influence of geometry on the optical properties of metallic optical filters. By looking at the spectral and transmission properties of the device, which is composed of a series of cross-shaped nanoapertures (e.g. Lin et al., Optics Express, 2011), as a function of the geometrical parameters and incident polarisation we are able to tune the colour filtering and sensing properties enabling a range of applications including biomolecular sensing and fluorescence detection.

9668-43, Session 2C

The Raman scattering in optical sensor

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This paper treats the theory of distributed optical fiber sensing measurement used in the monitoring of the structures civil, like tunnels, bridges, buildings, dams, pipeline... While resorting to distributed temperature sensors Raman scattering, we present a theoretical and simulation measurement of temperature. We highlight the effect of distance in temperature measurement in particular the work in this article provides the equation which shows well the relationship between the temperature and distance in optical fiber. The results indicate that the anti stokes signal is strongly dependent on the temperature, therefore the temperature varies slightly by changing the point of measurement.

9668-44, Session 2C

Tunable microwave notch filter created by stimulated Brillouin scattering in a silicon chip

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A recent demonstration of stimulated Brillouin scattering (SBS) in silicon enables strong photon-phonon interactions in a CMOS compatible platform. However, nonlinear losses in the silicon waveguide limit the amount of SBS gain that can be achieved to around 4 dB. Such a low gain is hardly usable for conventional signal processing applications based on SBS. In this work we utilise a technique to harness this modest SBS gain in silicon, creating a high performance, energy efficient microwave photonic notch filter. This demonstration represents the first functional device for signal processing based on SBS in silicon nanowires and forms the crucial first steps towards creation of a high resolution radio-frequency (RF) signal processor monolithically integrated in a silicon chip, which will be a disruptive technology for next generation radio-frequency systems with wide range of applications.

The results presented in this work were enabled by a 1 cm silicon nanowire with a cross section of 220 by 480nm, supported by a silica pillar with a 50nm width. Such a structure guarantees high confinement of the optical and acoustic modes allowing an efficient SBS interaction. We achieved 1dB of forward-SBS (FSBS) gain using 30mW of coupled pump power. The measured linewidth and Brillouin frequency shift were 98MHz and 8.72GHz respectively. The centre frequency of the notch in the RF domain can be tuned simply by changing the frequency of the SBS pump. We were able to continuously tune the notch frequency over a 6 GHz range, while maintaining the notch suppression above 48dB.

9668-45, Session 2C

Integration of upconversion nanocrystals into monolithic glass for high-performance photonic composites

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Integrating optically active nanoparticles in a monolithic material to create outperforming properties and new functions plays an essential role in both photonics research and technology. Of the various materials available to incorporate nanoparticles, glassy matrix has been attractive towards next-generation integrated photonic composites and devices.

To date, the almost exclusively used approach to achieve nanoparticles-embedded glass is the so-called glass ceramics method, which relies on heating glass to mobilize ions, crystalize in situ, and grow nanoparticles in the glass crystallization temperature range . However, this technique lacks a compositional and morphological control over in situ grown nanoparticles in glass, particularly for lanthanide-doped nanoparticles.

In this work, we have overcome the challenge by developing the direct doping method, whereby as-prepared lanthanide-doped nanoparticles are embedded in the glass by adding nanoparticles to the glass melt. We selected $LiYF_4$:Yb,Er and $NaYF_4$:Yb,Tm upconversion nanoparticles and tellurite-based glass as components. The tellurite glass can have sufficiently low viscosity to disperse these nanoparticles at temperatures below the decomposition temperature of nanoparticles. We optimized the temperature at which the nanoparticles are doped into glass melt and the dwelling time of the nanoparticles in the glass melt to suppress the dissolution of nanoparticles but permit them to disperse appropriately. We achieved a glass, which contains a large portion of survived nanoparticles that are well distributed in the glass matrix. The glass composites fabricated demonstrate nanocrystalline photonics properties. To the best of our knowledge, we have for the first time incorporated $LiYF_4$ and $NaYF_4$ upconversion nanoparticles in tellurite-based glass.

9668-46, Session 2C

Multipolar third harmonic generation in magnetic fishnet metamaterials

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Optical metamaterials can manipulate electromagnetic waves in unique ways, including light refraction and radiation. Recently optical harmonic generation from metamaterials has become increasingly important, as they provide strong field confinement that could boost the nonlinear conversion efficiency at the position of optical resonances. Moreover the metasurfaces provide magnetic resonances that could alter the radiation pattern of the emission, resulting in harmonic generation from magnetic dipoles and higher order multipoles, thus manipulating the nature of the nonlinear process. Here we report on the observation of enhanced third harmonic generation (THG) from Metal/Dielectric/Metal plasmonic fishnet metamaterials when pumped with one-picosecond laser pulses at telecommunication wavelengths (1557 nm). We have studied the radiation pattern of the THG signal and have provided a direct proof of its multipolar origin.

The tri-layer fishnet is composed of 25nm magnesium fluoride layer sandwiched between 20 nm gold films. The layers are perforated by rectangular holes (350 nm?190 nm) forming 500 nm square lattice. The pump laser is highly focused on the metamaterial, which results in THG at 519.5 nm. The signal is captured using confocal microscopy and the Fourier plane imaging provides information about the angular distribution of the radiation. We adopted theoretical model accounting for the symmetry of plasmonic currents in the layers leading to magnetic-dipolar or higher-order multipolar modes, which matches well our measurements. The contribution of the magnetic resonance in the harmonic generation provide new directions for manipulating the optical nonlinear process, which will help establishing ultra-compact nonlinear optical media for developing novel types of lasers and other nonlinear optic applications.

9668-47, Session 2C

Complete one-to-two coherent photon conversion in dispersion-engineered nonlinear waveguides

Alexander S. Solntsev, Andrey A. Sukhorukov, The Australian National Univ. (Australia)

A recent proposal [Nature 478, 360–363 (2011)] to utilize coherent photon conversion for scalable quantum computing architecture has generated a lot of interest. The potential advantages of this approach include deterministic multiqubit entanglement gates, high-quality heralded single- and multiphoton states free from higher-order imperfections and robust, high-efficiency detection. Whereas dispersion effects were neglected in the original study, we show that special dispersion engineering of nonlinear optical waveguides can drastically increase the efficiency of one to two photon conversion, with the possibility to reach 100% conversion at a finite propagation length. This is a nontrivial result due to complex dynamics involving the one- and two-photon states across a range of optical frequencies.

We consider coherent conversion of a pump photon into signal and idler photons in media with cubic nonlinearity through four-wave mixing, involving a high-intensity control wave. The dynamics of the coherent photon conversion is determined by the phase mismatch of the four-wave-mixing process across a range of signal and idler photon frequencies. Whereas it is generally accepted that most efficient conversion occurs in the regime of phase matching, we find that the shape of the mismatch dependence around the phase-matching point plays a critically important role in the high-conversion regime. We determine optimized cubic dispersion shape which allows complete conversion efficiency at a fixed normalized propagation distance, followed by a long region of very high (99%) conversion. We anticipate that this work will open new avenues for realization of coherent photon conversion in nonlinear optical waveguides.

9668-48, Session 2C

Nonlinear adiabatic couplers for tunable photon-pair Bell-state generation with spatial pump filtering

Che Wen Wu, Alexander S. Solntsev, Tong Liu, The Australian National Univ. (Australia); Frank Setzpfandt, Australian National Univ. (Australia); Andreas Boes, Christian Will, Arnan Mitchell, RMIT Univ. (Australia); Dragomir N. Neshev, Andrey A. Sukhorukov, The Australian National Univ. (Australia)

Nonlinear waveguides enable the integration of single and multiple photon sources and quantum logic gates on an integrated quantum photonic chip. Yet one of the major challenges in such systems is separating the generated entangled photon pairs from the pump. In this work, we employ nonlinear adiabatic couplers to generate spatially entangled photon pairs through spontaneous parametric down-conversion (SPDC) while simultaneously providing spatial pump filtering and keeping photon-pair states pure. The proposed scheme consists of two adiabatic couplers, where generated photons can also couple between the central waveguides. By designing the coupling strength of the waveguides, the SPDC phase mismatch, and the pump amplitudes in the two central waveguides, we can obtain a variety of spatially entangled bi-photon states, which exit through the waveguides at the edge of the structure. At the same time, the pump remains localized in the central waveguides.

We characterize experimentally adiabatic couplers fabricated in lithium niobate. We observe that the pump photons at 671 nm wavelength coupled to a central waveguide mostly remain in the same waveguide at the output, achieving filtering ratio of 20 dB at the outer waveguides. We also perform classical characterization at the SPDC wavelength of 1340 nm, and observe that light fully couples from the central input waveguides to the outer waveguides at the output. These results confirm the correct chip design, demonstrating its capability for generation of photon pairs which non-classical properties can be revealed by correlation measurements according to our theoretical analysis.

9668-49, Session 2C

Tunable entangled photon-pair generation in a quadratically nonlinear directional coupler

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Integrated optical platforms can enable the realization of complex quantum photonic circuits for a variety of applications including quantum simulations, computations, and communications. The development of on-chip integrated photon sources, providing photon quantum states with on-demand tunability, is currently an important research area. A flexible approach for on-chip generation of entangled photons is based on spontaneous nonlinear frequency conversion, with possibilities to integrate several photon-pair sources and realize subsequent post processing using thermo-optically or electro-optically controlled interference. However, deterministic postprocessing can only provide a limited set of output states, whereas quantum gates with probabilistic operation are needed to generate arbitrary two-photon states

We propose and experimentally demonstrate an integrated photon-pair source enabling wide-range optical tunability of the output entangled state, without a need for quantum gates and fundamentally exceeding the range of on-chip generated biphoton quantum states accessible in previous studies. We achieve this by combining the processes of spontaneous parametric down-conversion (SPDC) and interference of the generated photons in a quadratic nonlinear waveguide coupler in lithium niobate. By adjusting the phase difference between the pump beams and the phase mismatch, the output photon pairs can be tuned between un-entangled product states and maximally entangled Bell states. We characterized the biphoton states by spatial correlation measurements and quantum tomography, and observed a good agreement with our theoretical predictions. In particular, the experimental fidelity of the N00N state is 0.93. We believe that the demonstrated concept can be an important building block for integrated quantum optics.

9668-50, Session 2C

All-optically reconfigurable arbitrary two-qubit state generation in inhomogeneously poled nonlinear waveguides

James G. Titchener, Alexander S. Solntsev, Andrey A. Sukhorukov, The Australian National Univ. (Australia)

The generation of non-classical states of light is important for developing quantum technologies such as communication, enhanced measurement and computing. Traditionally quantum states of light are created using bulk optics, however more complex applications require the use of integrated optics to reduce decoherence. We propose an integrated scheme that can be engineered to produce any spatially entangled state. Furthermore real time re-configurability of the devices' output quantum state can be achieved by varying a set of classical driving lasers, allowing any state in a chosen multi-dimensional quantum space to be switched to instantaneously.

The device consists on an array of coupled quadratic nonlinear waveguides in which entangled photon pairs are produced via spontaneous parametric down-conversion (SPDC) by laser driving the waveguides. Special poling patterns in each waveguide steer the wavefunction to desired states .The waveguide separation is chosen so that the pump lasers driving SPDC don't couple between waveguides, but down-converted photon pairs can couple into

neighboring waveguides. This means that the unique poling pattern in each waveguide can be addressed individually with a chosen intensity and phase of the pump laser. Thus pumping multiple waveguides simultaneously enables controlled interference between the states produced when each waveguide is pumped individually. This way arbitrary linear combinations of a number of quantum states can be created, spanning an entire quantum space just by varying the pumping profile. We show how this can allow pump filtering, as well as the optically reconfigurable generation of any two-qubit state.

9668-51, Session 2C

Quantum-classical correspondence of spontaneous down-conversion and sum-frequency generation in waveguide arrays

Diana Antonosyan, James G. Titchener, Alexander S. Solntsev, Andrey A. Sukhorukov, The Australian National Univ. (Australia)

Development of quantum chips with integrated sources of entangled photons based on spontaneous parametric down-conversion (SPDC) in nonlinear waveguides is actively progressing due to improvements in fabrication technology. Future mass-production of such chips for end-user applications will demand efficient quality-control procedures. We identify a correspondence of quantum photon-pair generation through SPDC and classical sum-frequency generation (SFG) in waveguide arrays, such that the latter process can be used for fast quality control based on classical optical measurements.

Our approach is applicable to arrays of coupled quadratically nonlinear waveguides, even in presence of spatially inhomogeneous linear absorption. We formulate analytical solutions and reveal a direct correspondence between the elements of the two-photon wavefunction and the classical SFG signal at different output waveguides for various input conditions. This allows the expected quantum state produced by a device to be inferred simply using classical SFG measurements. Furthermore we show how this classical-to-quantum analogy can be used to determine the spectral properties of photon generation through SPDC across a broad range of frequencies.

We demonstrate an application of this approach to parity-time (PT) symmetric structures, where unconventional regimes of light manipulation including unidirectionality and invisibility can be realised, taking advantage of PT-symmetry breaking transition for optical modes. We consider a PT-structure consisting of two coupled quadratic nonlinear waveguides, where one waveguide is lossy. We show that modal PT-symmetry breaking significantly affects the quantum correlations of the photon pairs generated through SPDC and that the classical SFG process emulates the behaviour of the biphotons.

9668-156, Session PMon

Structural, linear, and nonlinear optical studies on annealed Mn doped ZnO thin film investigated using z-scan technique under cw regime

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We present the studies on third-order nonlinear optical properties of annealed manganese doped zinc oxide thin films at different doping concentration. Zinc oxide (ZnO) is a well-known II–VI semiconductor having a direct band gap of 3.37eV. Doping of Mn into ZnO lattice increases the functionality of the ZnO. The present study reveals that the introduction of Mn in to ZnO and annealing leads to significant changes in the third order nonlinearity. Mn doped ZnO thin films were prepared by RF magnetron sputtering technique. The films were annealed in the temperature range 200–400?C for 2hrs. Nonlinear optical measurements were carried out by employing the Z-scan technique using a He–Ne laser operating in continuous wave mode at 633 nm. The Z-scan results reveal that the films exhibit self-defocusing thermal nonlinearity. The third-order nonlinear optical susceptibility ?(3), of 5wt% Mn doped ZnO thin film annealed at 400oC was found to be of the order of 10?3esu.The Atomic force microscope analysis reveals the dependence of grain size and roughness of the films on Mn concentration. Optical limiting studies were carried out for various input power levels. Optical clamping of about ~8mW was observed indicating the possible photonic device application.

9668-157, Session PMon

Slow light in aperiodic photonic superlattices and waveguides

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Nowadays, slow light with an extremely low group velocity has found a number of significant applications in the field of optics and photonics. Particularly this phenomenon is a promising solution for optical true time delay line; the spatial compression of optical energy; the buffering and time-domain processing of optical signals; the enhancement of linear and nonlinear optical effects. Highly dispersive photonic structures are especially attractive for generating slow light, because they are compatible with on-chip integration and characterized room-temperature operations.

In the present paper, we investigate the slowing light in one-dimensional aperiodic photonic superlattices and Bragg reflection waveguides on their basis. All proposed structures have been modeled using the transfer matrix formalism. The spectral behaviors, the slowing-down factor, the group velocity and the phase time of aperiodic photonic band-gap structures were studied. The group velocity of aperiodic structures built according to certain deterministic substitutional rules has been studied and compared to those of periodic structure. Besides, on the basis of our previous investigation [1, 2], Bragg reflection waveguides with aperiodic arrangement of the layers in the cladding were analyzed from the viewpoint of obtaining slow light. The effect of the cladding aperiodicity on the slowing down of light in Bragg reflection waveguides was also discussed.

[1]. V.I. Fesenko, V.R. Tuz, Pedro Pablo Rocha Garcia, I.A. Sukhoivanov, Dispersion properties of a one-dimensional aperiodic OmniGuide structure. Proc SPIE 9200, p. 920017(1-7), 2014.

[2]. V.I. Fesenko, Aperiodic birefringent photonic structures based on Kolakoski sequence. Waves in Random and Complex Media. 24(2), 174-190, 2014

9668-158, Session PMon

Effect of BMITFSI to the electrical properties of methycelloluse/chitosan/NH4TF-based polymer electrolytes

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Solid polymer electrolyte (SPE) prepared using natural polymer are widely investigated as an important ionic conductor due to its biocompatibility and non-toxicity. However, low ionic conductivity in these SPE limits its application. Hence, many ongoing research are seeking possibilities to enhance the conductivity of SPE, which includes addition of plasticizers and fillers. Due to their distinct features, ionic liquids (IL), have been used as an alternative to plasticizers.
In this study, blended polymer electrolyte of methylcellulose (MC) and chitosan with ammonium triflate, (NH4TF) were prepared with different weight percentage of BMITFSI. The blending of polymers which results in new materials with improved physicochemical and mechanical properties has received fully attention in past several years. Researchers have shown that blend films from chitosan and methylcellulose (MC) has been shown to have improved mechanical and physical properties since these two polysaccharides have compatible structures. The SPE was prepared by solution casting technique and characterized using electrical impedance spectroscopy (EIS) to measure its ionic conductivity. Samples with 45 wt% of BMITFSI exhibit the highest conductivity of 3.98 x 10-4 Scm-1 at ambient. The tendencies of dielectric constant, over the concentration of BMITFSI propose that the number of charge carriers strongly influences the increase in conductivity.

9668-159, Session PMon

Gate dielectric prepared from the regenerated silk fibroin for organic thin film transistor

Hyoung-Joon Jin, Inha Univ. (Korea, Republic of)

The surface energy of the gate dielectric greatly affects pentacene deposition conditions, which leads to the changing morphology and microstructure of pentacene, and consequently to changes in charge transport and organic thin film transistor performance. It is expected that the surface energy change of a gate dielectric can cause a change in the grain size of the pentacene because the growth mode of the film can be determined by the difference in surface energy between the pentacene and the gate dielectric. Therefore, in order to investigate in detail the effects of the pentacene morphology with respect to the surface energy of the gate dielectric, we controlled the surface energy of the silk fibroin (SF) gate dielectric. The surface energy of SF is related to the formation of the highly periodic crystalline regions in the SF. The crystal structure of SF depends on the crystallization method used, such as water annealing, ethanol, and methanol solution treatments. We controlled the degree of ?-sheet structure of SF using water annealing, ethanol and methanol solution treatments. Following the various crystallization methods, the surface energy of the gate dielectrics is controlled by adjusting the crystal structures of SF. We also follow the wettability behavior of the SF thin film surfaces by measuring the contact angle to determine the surface energy characteristics of SF thin films. Also, the morphology of the pentacene deposited on SF thin films was observed for application SF as a gate dielectric.

9668-160, Session PMon

Fabrication of translucent nanoceramics and its behavior in cell response

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Typical transparent ceramics are fabricated by pressure-assisted sintering techniques such as hot isostatic pressing (HIP), spark plasma sintering (SPS), and pressure-less sintering (PLS). However, a simple energy efficient production method remains a challenge. In this study, we describe a simple fabrication process via a facile filtration system that can fabricate translucent hydroxyapatite based ceramics. The translucent pieces yielded from filtration exhibit optical transmittance that was confirmed by UV spectroscopy. Briefly, the morphology and size of ceramic nanoparticles, the filtration pressure and filtration time are important parameters discussed. This method could be further applied to prepare other translucent functional ceramics by controlling the size and morphology of ceramic particles. Moreover, the results from filtrated samples indicate that those hydroxyapatite nanoparticles bringing nano-spherical morphologies are more likely to form a highly-packed structure by comparing with those nano-rod strontium substituted nanoparticles. Later on, the cell response was studied and examined as further evidence to support such novel biomaterial interface can be utilized as detecting mirror to trace the cell behavior in future.

9668-161, Session PMon

Nano TiO2-activated carbon composite electrodes for supercapacitor

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A symmetrical (p/p) supercapacitor has been fabricated by making use of nanostructured Titanium oxide–activated carbon (AC) composite electrodes for the first time. The composites have been characterized by FESEM, optical microscopy and XRD. Electrochemical properties of the prepared nanocomposite electrodes and the supercapacitor have been studied using cyclic voltammetry (CV) and AC impedance spectroscopy in 0.1N HClO4 and 0.1 N Na2SO4 as electrolyte. The TiO2–AC nanocomposite electrode showed a specific capacitance of 122 F/g for 1:1 composition. The electrochemical behavior of the neat TiO2 nanoparticles and its optical studies has also been studied. The galvanostatic charge-discharge test of the fabricated supercapacitor showed that the device has good columbic efficiency and cycle life. The specific capacitance of the supercapacitor was stable up to 5000 cycles at current densities of 2,4,6 and 7mAcm-2.

9668-162, Session PMon

Studies on structure, thermal, and mechanical properties of nano-composites of organically modified monmorillonite clay with some polymer

Ashok Rao, Manipal Institute of Technology (India)

A series of polymer-organically modified montmorillonite (OMMT) clay composites of varying compositions have been prepared by solution casting method. The polymers used for the preparation of composites are, celluloseacetatebutyrate, polymethylmethacrylate, polyvinyl chloride, polyvinyl acetate. The nano composites have been characterized by powder X-ray diffraction (XRD), fourier transform infrared spectroscopy (FTIR) and scanning electron microscopy (SEM) analyses. Analyses of the formation and structural features of the composites based on XRD and FTIR data indicated the formation of intercalated or partially exfoliated structures. Thermal and mechanical properties of the composites have also been investigated by differential scanning calorimetry and tensile strength tests. The results indicated significant improvement of specific properties in the composites compared to the individual reactant components which may be ascribed to the intercalation of the polymers with the clay.

9668-164, Session PMon

Enhanced emission in Dy doped Ge28.125Ga6.25S65.625 glass ceramics

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We have annealed Ge28.125Ga6.25S65.625 glasses doped with 0.5% Dy to create glass-ceramics in order to examine the formation of the different crystalline phases and the local chemical environment of the rare earth ions (REI). We found that the density and mechanical hardness of the glass can be improved by increasing the annealing time. Raman scattering spectra indicated that GeS2 crystals were dominant on the surface of the glasses while Ga2S3 crystals were mostly in the interior. Significant enhancement of the emission at 2.9um was achieved in glass-ceramics produced using prolonged annealing times. Elemental mapping showed clear evidence that, in the interior of the glass-ceramics, Ga2S3 crystalline grains with a size of 50 nm were dispersed in a Ge-S glass matrix. The REI could only be found near the Ga2S3 crystalline grains. From the unchanged lineshape of the emission at 2.9um and lack of splitting of the absorption peaks, we concluded that the REI were bonded to Ga on the surface of the Ga2S3 crystals.

9668-165, Session PMon

Synthesis of graphene oxide/sodium silicate nanocomposite using sodium silicate solution

Sung Jin An, Kumoh National Institute of Technology (Korea, Republic of)

Silicon alkoxide is the typical precursor used in the synthesis of graphene-silica composites; however, it is a toxic and relatively expensive material. Sodium silicate solution, on the other hand, is used

industrially as a precursor in sol-gel processes for the production of silica. It is water-soluble and cheaper than silicon alkoxide and may be a suitable replacement in the preparation of graphene-silica composites. Graphene oxide/sodium silicate (G-O/Na2SiO3) sols were prepared from different concentrations of sodium silicate solutions and the pH of the sols was varied using HCl. The most stable G-O/Na2SiO3 sol was formed at pH 11, using 0.1 g of sodium silicate solution. We confirmed that the rG-O/Na2SiO3 nanocomposite contains particles with irregular shapes and sizes of a few hundred nanometers. The rG-O/Na2SiO3 nanocomposite also exhibited the lowest sheet resistance of 255.8 Ω/?.

9668-166, Session PMon

Fabrication and optical characterization of a 2D metal periodic grating structure for cold filter application

Atsushi Motogaito, Masanori Kito, Hideto Miyake, Kazumasa Hiramatsu, Mie Univ. (Japan)

A cold filter that simultaneously achieves the reflection of infrared light and transmission of visible light was fabricated using a 2D metal periodic grating structure. A conventional dielectric multilayer film was used, which had abrupt filtering characteristics; however, there were problems with the incident angle, temperature, and polarization. To solve these problems, a 2D metal periodic grating structure was applied. This type of structure has the advantage that it does not depend on polarization. In this study, the 2D metal periodic grating structure, comprising an Au layer and electron beam resist layer, was fabricated by electron beam lithography. The optical characterization of this structure in the visible light region was then conducted using a spectrometer.

The relationship between the optical properties and period of the double-layer, 2D grating structure was characterized. In particular, reflectance for the entire visible light spectrum decreased when the period was 800 nm and 1 ?m. The measurement results suggested that by changing the spacing between upper and lower metal layers from 270 to 370 nm, the wavelengths with the minimum and maximum reflectance were shifted. From the simulation results, it can be considered that the interference between the upper and lower layers and the surface plasmon resonance between the metal and resist layers occur simultaneously. Therefore, in the visible light region, the controlling reflectance and transmission spectra were controlled by the structure of the 2D metal periodic grating.

9668-168, Session PMon

Density dependence of carrier dynamics in CH3NH3PbBr3 perovskite

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The excellent light harvesting properties and potentially low cost fabrication of organometal halide perovskites are attracting great attention in their use in the solar cell fabrication. Apart from the general advantages of organic-inorganic perovskite, CH3NH3PbBr3 shows a relatively greater energy bandgap (~2.3eV) compared to CH3NH3PbI3. Therefore, it is suitable for the use as the top cell of tandem solar device [1, 2]. Despite previous photophysical investigations, there remains an incomplete understanding of photophysics underlying CH3NH3PbBr3 perovskite solar cell operation [3-7]. Here we will use steady-state and time-resolved photoluminescence (PL) techniques to investigate the photophysical behavior of CH3NH3PbBr3 perovskite focusing on the carrier dynamics under illumination. Our research reveals that CH3NH3PbBr3 exhibits an irregular change in the PL intensity as the level of excitation intensity from the laser source is modified. We investigate the variations of fluorescence under different illumination conditions and make the following observations: under the low intensity illumination, the PL intensity remains at a stable level as the exposure time increases; by contrast, a high intensity illumination results in a fast PL quenching process on the same samples. We propose that the density of photoexcited carriers is contributing to this photophysical phenomenon because it greatly impacts on the defect and Auger recombination directly influencing the PL intensity.

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9668-169, Session PMon

High efficiecy quantum-dot light-emitting diodes with polyaniline-poly-(p-styrenesulfonic acid) interlayer

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For the solution-spin-cast quantum-dot light emitting diodes (QD-LEDs), organic bilayers of poly(N-vinylcarbozole) (PVK)/poly(3,4-ethylenedioxythiophene) polystyrene sulfonate (PEDOT:PSS) have been widely used as the hole injection/transport layer due to high p-type conductivity. More balanced electron/hole charge injection is crucial for high electrical and electroluminescence efficiency of QD-LEDs. Herein we report on the improved performance of QD-LEDs with polyaniline-poly (p-styrenesulfonic acid) (PANI:PSS) interlayer. The insertion of PANI:PSS between PVK/PEDOT:PSS shifted the overall electronic energy levels of PVK. Ultraviolet photoelectron spectroscopy (UPS) revealed the substantial downshift of the HOMO levels of the PVK by 0.22 eV so that reduced the hole barrier at QD/PVK from 1.45 to 1.23 eV. Since the hole barrier of QD/PVK is the largest one, the reduced hole barrier at QD/PVK could contribute high p-type conductivity for QD-LEDs. The hole-only devices with PANI:PSS interlayer presented higher hole conduction capability that those without PANI:PSS. More importantly, the QD-LEDs with PANI:PSS interlayer exhibited superior luminance and luminous current efficiency that those without PANI:PSS. We further discuss the electronic energy level alignment of the QD-LEDs as a function of PSS content in PANI:PSS. Atomic force microscopic, UV–Vis absorption spectroscopic, and Fourier-transform infrared spectroscopic analyses are also provided. We believe that the insertion of PANI:PSS interlayer, capable of shifting the electronic structure of the next organic overlayer and increase the p-type conductivity, can be exploited to improve the performance of PVK/PEDOT:PSS-based electronic and optoelectronic devices.

9668-170, Session PMon

Emission-color-tuned light-emitting diode microarrays with InGaN-based multishell nanotube heterostructures

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The nanostructure lighting sources with well-defined emission wavelengths are sufficiently recognized as important component for future optoelectronic integrated circuitry. We demonstrate the GaN-based multishell nanotube light-emitting diode (LED) microarrays with composition-modulated m-plane InxGa1–xN/GaN multiple quantum-wells (MQWs). The nanostructure-LED arrays were fabricated by selective-area metal–organic vapor-phase epitaxy of ZnO nanotube arrays on c-sapphire, followed by heteroepitaxial radial coating of GaN p–n junction with InGaN/GaN MQWs. The emission wavelengths were

controlled in the visible spectral range of green to violet by varying the indium mole fraction of the InxGa1–xN MQWs in the range 0.13 ≤ x ≤ 0.36. Spatially-resolved cathodoluminescence spectroscopy and high-resolution transmission electron microscopy revealed well-defined formation of radial heterostructures. The nanotube LED microarrays exhibited electrical rectification of a p–n diode with strong electroluminescence emission above a turn-on of 3.0 V. Homogeneous emission from the entire area of the nanotube LED arrays was achieved via the formation of MQWs with uniform QW widths and composition via heteroepitaxy on the well-ordered nanotube arrays, as confirmed via comparative study on light emission of nanotube LED arrays by electroluminescent and photoluminescent spectroscopy. Importantly, the nanotube p–n LED microarrays exhibited strong and wavelength-invariant electroluminescence emission above a turn-on, because both the quantum-confinement Stark effect (QCSE) and band filling were suppressed due to the lack of spontaneous inherent electric field in the nanotube nonpolar MQWs. Hence, our method of fabricating nonpolar LED microarrays with well-tuned emission colors provides a general straightforward pathway toward heterogeneous monolithic integration of nonpolar photonic and optoelectronic devices on commonly used c-sapphire and Si substrates.

9668-171, Session PMon

Dynamic evaluation and control of blood clotting using a microfluidic platform for high-throughput diagnostics

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Microfluidic technology has the potential to revolutionise blood-clotting diagnostics, particularly due to the ability to recreate key physiological blood flow conditions such as shear rate. Working in this direction, recent microfluidic approaches have focused on developing high-throughput platforms generating multiple shear rate conditions, mainly through the use of parallel microchannels and injury-model arrays with varying sizes. However, questions remain on the efficacy of these methods and the complexity of clinical interpretation of large amount of experimentally generated data. In this paper we present a customised dynamic microfluidic system, which evaluates the blood clotting response to multiple conditions of shear rate on a single microchannel containing a vessel-narrowing injury model. The system can achieve high-throughput testing through use of an advanced fluid control system, which provides with rapid and precise regulation of the blood flow conditions in the platform. Further, characteristics of the blood clotting response are analysed using concepts of control theory, namely system identification. In this way, a reduced set of parameters from a recently developed model describes the clotting properties of a blood sample in response to a wide range of shear rate conditions. We present experimental results that demonstrate the potential of this platform to develop into a high-throughput, low-cost, blood-clotting diagnostics device.

9668-172, Session PMon

Enhancement of the melting threshold of nanoparticles in Young's modulus-enhanced hybrid ceramic composites

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Metallic nanoparticles are widely used for data storage, bio-imaging and light trapping due to their strong plasmonic resonance [1-3]. However, the thermal stability of metallic particles decreases as the size of the metallic particles is reduced. In this paper, we report on the demonstration of the enhancement of the melting threshold of metallic nanoparticles after the incorporation into the Young's modulus-enhanced hybrid ceramic composites.

Metallic nanoparticles were incorporated into the hybrid ceramic composites with organic-inorganic components, which increase the solubility of nanoparticles. An enhancement of the Young's modulus has been achieved by increasing the ratio of the inorganic components.

To confirm the enhanced melting threshold, we performed experiments on irradiance induced melting of single particles. When irradiated by a femtosecond pulsed laser beam, the metallic particles can be melt due to the photo-heating effect [1]. The melting threshold of single nanoparticles has been studied by measuring the back scattering spectrum after irradiating with a femtosecond laser at a wavelength of 820 nm. The resonant peak in the back scattering spectrum corresponding to the plasmonic resonance shifts after melting due to the shape changes. A three-time enhancement in melting threshold effect has been confirmed.

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9668-174, Session PMon

A homeostatic, chip-based platform for zebrafish larvae immobilization and long-term imaging

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Zebrafish larvae are ideal for toxicology and drug screens because of their transparency, small size and similarity on genetic level to humans. Using modern imaging techniques cells and tissues can be visualized and followed over days in multiple zebrafish. Yet continued imaging experiments require moisture and heat control which is not always available for all imaging platforms. An ideal solution for long term imaging would therefore be an affordable, mounting configuration for a large number of larvae adaptable for different experiments, ensuring temperature as well as media homeostasis over several days. 3D printing for rapid prototyping is particularly suitable for this purpose as it offers both quick turnaround time from design to prototype as well as flexibility in design. We study neural regeneration in zebrafish. Regeneration is limited in humans, but zebrafish recover from neural damage within days. Yet, the underlying regenerative mechanisms remain unclear. We developed an agarose based mounting system that holds the embryos in defined positions along removable strips. Homeostasis is ensured by channels circulating buffer and heated water. This allows to image up to 120 larvae simultaneously. We are designing a platform with experimental groups controlled by their own microfluidic media flow. Taken together, we offer a low cost, highly adaptable solution for long term in-vivo imaging. Its flexibility and the low-volume, high larvae ratio will allow screening of small compound libraries. It will contribute to the understanding of the mechanism behind spinal cord regeneration as well as yield potential new active drugs in neural regeneration.

9668-175, Session PMon

Testing organic toxicants on biomicrofluidic devices: why polymeric substrata can lead you into trouble

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Advances in microfabrication technologies and manufacturing over last decade, allowed for inexpensive prototyping of microfluidic chip-based devices for biomedical studies in biocompatible and optically transparent elastomeric polymers such as poly(dimethylsiloxane) (PDMS) and thermoplastics such as poly(methyl methacrylate) (PMMA). More recently, advanced additive manufacturing technologies such as stereolithography (SLA), capable of reproducing feature sizes less than 50 µm, pave a way towards a new generation of microfabrication techniques. The latter promise new methods to enable accelerated design, validation and optimisation of optical-grade biomicrofluidic Lab-on-a-Chip (LOC) devices. The main limitation of virtually all polymers (both conventional elastomers and modern SLA substrata) that are used to manufacture LOC devices, however, is their significant hydrophobicity. Conventionally the hydrophobic properties were postulated to impede wetting and priming of the polymeric chip-based devices. Such issues were often solved with plasma treatment or ethanol priming to help wet the polymeric substrata and also reduce the nucleation and persistence of air bubbles. In this work, we present evidence that use of hydrophobic polymers is a significant impediment in performing ecotoxicity tests of organic chemicals on biomicrofluidic devices. We report on electrostatic interaction between polymers and toxicants that lead to non-covalent adsorption and rapid depletion of chemicals from the tested media. This introduces a significant bioanalytical bias irrespectively of the fact that LOC tests are preformed under continuous perfusion. We demonstrate innovative solution of the problem by demonstrating applications of a new thiol-ene-epoxy hydrophilic polymers such as 322 OSTEmerX Crystal ClearTM as well as selected surface modifications and coating of PDMS, PMMA and SLA substrata with chitosan and PEG that render them hydrophilic.

9668-176, Session PMon

Multiphoton life time imaging microscopy reveals alteration in free to bound NADH ratio associated with Inhibition of metabolic enzymes activities in pancreatic cancer cells

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Measurment of endogenous free to bound NAD(P)H relative concentration in living cells is a useful method for monitoring aspects of cellular metabolism, because the NADH/NAD+ reduction-oxidation pair is crucial for electron transfer through the mitochondrial electron transport chain. Variations of free and bound NAD(P)H ratio are also implicated in cellular bioenergetic and biosynthetic metabolic changes accompanying cancer.

This study uses two-photon fluorescence lifetime imaging microscopy (FLIM) to investigate alteration in free to bound NADH in pancreatic cancer cells treated with two enzymatic and metabolic inhibitors Oxythiamine(OT) and Lonidamine(LNT) for 2, 24 and 48 hours. Oxythiamine (OT), an analogue of anti-metabolite, inhibitor for transketolase enzyme and suppress the nonoxidative synthesis of ribose and induce cell apoptosis by causing a G1 phase arrest in vitro and in vivo. Lonidamine is a mitochondrial Hexokinase enzyme inhibitor, specifically inhibit glycolysis by lowering the number of glucose molecules that enter the glycolytic pathway, as well as to affect membrane integrity.

For LNT treatment , The results showed statistically signifficant ($p>0.05$) differences between treated and untreated cells were observed after 2 hours and 48 hours After 2 hours of LNT treatment average lifetime of NADH signifficantly decreased accompanied by increase of free-to-bound NADH ratio and shortening of bound NADH in imaged cells. Such changes are consistent with metabolic changes characterised by increased glycolysis. After 48 hours signifficant increase for average lifetime and long and short lifetime components and decrease in free to bound NADH ratio for LND treated cells consistent with strong glycolysis inhibition.

For OT treatment the trends are opposite. Increasingly with time from treatment the higher differences in shortening of average lifetime, increase in free to bound NADH ratios and very signifficant shortening of bound NADH lifetime for 48 hours from treatment. Also an increase in NADH intensity observed in photon intensity image for OT treated cells as compared to untreated cells is consistent.

9668-177, Session PMon

Evaluation of additive element to improve PZT piezoelectricity by using first-principles calculation

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Recently, piezoelectric material has a very important potential for functional material which configure Bio-MEMS (Biological Micro Electro Mechanical Systems) actuator and sensor. Specifically, in implementation of piezoelectric material for Bio-MEMS, thin film fabrication by sputtering method is made from the viewpoint of miniaturization. Furthermore, in piezoelectric material, perovskite type material composed of ABO_3 has a high piezoelectricity. Then, PZT (Lead Zirconate Titanate) as the perovskite type piezoelectric material is widely used since it is easy to produce and has high piezoelectricity. PZT has zirconium or titanium in the B site of ABO_3 structure. PZT has the features such as physical properties to greatly change by change in the B site composition ratio of zirconium and titanium. Thus, the B site greatly influences physical properties and therefore function improvement by additive element is tried widely. However, experimental method to lack in economy and quantitativeness is mainstream. Therefore, application of the result is difficult and new evaluation method of B site additive element for sputtering fabrication is necessary. Accordingly, in this research, search of an additive element at low cost and quantitative from the viewpoint of energy by first-principles calculation. First of all, the additive elements which capable of substituting for a B site of PZT were searched. Next, change of piezoelectricity was evaluated by change of crystal structure in a PZT system was introduced an additive element that substitution of the B site was possible. As a result, additive elements for the PZT B site capable of improving piezoelectricity were determined.

9668-178, Session PMon

Growth and characterization of a new nonlinear optical organic crystal: 3-nitroacetanilide

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A new nonlinear optical organic material, 3-nitroacetanilide (3NAA), also known as N-[3-nitrophenyl]acetamide, has been synthesized and grown as a single crystal by the slow evaporation technique in organic solvents. The grown crystals have been characterized by morphology study. The crystals are pyramidal and have pale yellow color. Surface examination shows step like pattern in optical micrograph. The Scanning Electron Micrograph shows the layered growth of the crystal. The Differential Scanning Calorimeter plot shows no phase change until the melting point (152°C). The density of the crystals is 1.410 g/cc and the crystals are soft. The crystals are transparent in the visible region till 430 nm. 3NAA crystallizes with 8 molecules in a monoclinic unit cell in the non-centrosymmetric point group 2, space group $P2_1$ [1]. Refractive indices of this optically biaxial crystal along the three crystallo-physical axes have been measured at 633 nm. The optical second harmonic generation efficiency of the crystal at 1064 nm is about one-third of that of the urea crystal, measured by powder method using Nd:YAG laser. The results show that the 3NAA crystal can efficiently be used for up-conversion of infrared radiation into visible green light. [1] L. Mahalakshmi et al, Acta. Cryst. E58 (2002) o983.

9668-179, Session PMon

Resonance breakdown of dielectric resonator antennas on ground plane at visible frequencies

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Dielectric resonator antennas (DRAs) have been experimentally demonstrated recently as resonant elements in metasurfaces for applications at optical frequencies. As low-loss high-permittivity DRAs operate via displacement currents, they are less affected by Ohmic loss at optical frequencies compared to metallic resonators. Previously, we demonstrated an optical reflectarray and directional plasmonic couplers based on nonuniform arrays of DRAs that operate in their fundamental magnetic dipole mode on metal surfaces. In this configuration with a metallic ground plane, the resonance property of the DRAs in the visible frequency range is strongly affected by plasmonic effects. In this paper, we report our study of the observed resonance breakdown of DRAs on a metal surface due to increasing plasmonic confinement. The studied structure is a cylindrical DRA on a silver plane. In one case, the relative permittivity ?_d of the DRA is varied and the resonance breakdown occurs when ?_d approaches and becomes larger than the absolute value of the real part of the silver permittivity. In another case, the DRA ?_d is fixed and the operating frequency is varied. Similarly, the resonance breaks down when the operating frequency approaches the frequency where ?_d matched the real part of the silver permittivity. Electromagnetic simulations are conducted to help build a circuit model of the breakdown process. This study offers a guideline to design dielectric resonators in optical nanostructures.

9668-180, Session PMon

BOX effect sensitivity to fin width in SOI-Multi-FinFETs

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SOI-Multifin-FETs are placed to be the workhorse of the industry for the coming few generations and thus in a few years because their excellent transistor characteristics, ideal sub-threshold swing, low drain induced barrier lowering (DIBL) without pocket implantation and negligible body bias dependency.

The corner effect may also exist in the two lower corners; this effect is called the BOX effect, which can also occur in the direction X-Z. The electric field lines from the source and drain cross the bottom oxide and arrive in the silicon. This effect is also called DIVSB (Drain Induced Virtual Substrate Basing). The potential in the silicon film in particular near the drain is increased by the drain bias. It is similar to DIBL and result in a decrease of the threshold voltage.

This work provides an understanding of the limitation of this effect by reducing the fin width for components with increased fin number.

9668-181, Session PMon

The simulation analysis of different imaging methods in the ISAR Image system

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Inverse synthetic aperture imaging system is very important for moving target detection and recognition. And it can realize high resollution imaging compare to the conventional imaging laser system with scan mode. This paper analyzed three different kinds of methods used in the inverse synthetic aperture imaging system by simulating in MATLAB. The simulation system was based on the consideration of system structure, atmosphere, attenuation, background noise and target scatter characteristic. All the imaging methods' simulation were finished and analyzed.

9668-182, Session PMon

Calculation of the dynamic characteristics of micro-mirror based on thermal micro-actuators

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Micro-mirror element structure driven by thermal micro-actuators has been proposed. Micro-mirror has of 100x100 μm dimensions and is manufactured by the surface treatment technology methods of microelectronics. Thermal bimorph micro-actuator is a structure of aluminum and silica with polysilicon heater. The description of the sequence of operations process for micro-mirror element production has been presented. Structure heating and rotating mirrors were happened during electric current passing through heater. The process of heating and cooling patterns of thermal micro-actuators directly affected on the manufactured micro-mirror characteristics, and therefore the study of these processes is essential. Method for calculating of heating and cooling time, taking into account the effect of the structure geometry, the electrical characteristics of external influence and the environment has been discussed. We used method of electro-thermal analogy, so new method for the experimental determination of the dynamic characteristics has been proposed. The calculation results are in good agreement with the experimental data, allowing you to use them to determine the dynamic devices characteristics based on thermal micro-actuators.

9668-183, Session PMon

Efficient end-fire coupling of surface plasmons into silver

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End-fire coupling of light into a surface plasmon is a simple and compact coupling method with a range of potential uses in photonic circuitry. Although end-fire coupling has been successfully implemented in many coupling configurations, the coupling mechanism itself is not fully understood. Here, we present a semi-analytical study which models the coupling efficiency of an incident beam into a surface plasmon using an energy-conserving projection method. In previous work, we showed that, for an air-to-lossless-silver configuration, the coupling efficiencies could reach above 80% when the incident beam width and position are optimised for wavelengths in the range of 0.5-1.5 microns. Here we find that the coupling efficiencies remain higher than 80% with the addition of loss to the silver. In addition to the excitation of the primary surface plasmon, a secondary transversely propagating surface plasmon is observed to be excited simultaneously. We discuss the definition of the coupling efficiency in the presence of multiple modes in a lossy medium, and investigate how the presence of the secondary surface plasmon affects coupling of the optical beam into the primary surface plasmon.

9668-184, Session PMon

Parity-time anti-symmetric parametric amplifier

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Light propagation in waveguiding structures with spatially distributed sections of loss and gain can be analogous to quantum wavepacket dynamics governed by a parity-time (PT) symmetric Hamiltonian. Below a certain gain/loss level, such systems support PT-symmetric optical modes, which then exhibit the same average loss or gain. However when gain or loss is increased, the PT-symmetry of modes breaks, and a mode with the strongest gain dominates. The phase

transition associated with such PT-symmetry breaking opens new possibilities for light manipulation, such as PT-symmetric lasers.

Parametric amplifiers are commonly used as an integral part of optical setups enabling flexible wavelength conversion. Importantly, the amplification rate is determined by the pump, enabling ultrafast all-optical tunability.

We consider a directional coupler composed of two waveguides in quadratically nonlinear medium, where modes exhibit different loss in each waveguide. In the linear regime, at low light intensities, such coupler realizes PT-symmetric optical system. We analyse the process of optical parametric amplification based on nonlinear mixing between a strong pump, and signal and idler waves. We model the wave propagation using coupled-mode equations in the regime of narrowband and undepleted pump. We reveal the potential of PT-symmetric systems for optical parametric amplification, and identify a new regime of spectral PT anti-symmetry in such devices. Such devices can, on one hand, realize ultrafast spatial signal switching through pump-controlled breaking of PT symmetry, and on the other hand enable spectrally-selective mode amplification in analogy with PT lasers.

9668-185, Session PMon

Non-Hermitian quantum billiards for microcavity exciton polaritons

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Exciton polaritons are composite light-matter quasiparticles, which form in semiconductor microcavities in a strong light-matter interaction regime. Being bosons, exciton polaritons can condense into a macroscopically occupied quantum state – a Bose-Einstein condensate. In recent years, exciton polariton condensates have been extensively studied in the context of fundamental physics of quantum fluids, polariton lasers, and novel polariton-based optoelectronic devices. Importantly, exciton polariton condensates are open-dissipative in nature, thus the non-Hermitian character of the system must be considered. In this work, we experimentally demonstrate a non-Hermitian Sinai billiard for exciton polaritons, which is composed of a rectangular optical potential with a circular scatter in one corner. Within this billiard, we create and image single-particle eigenstates. Remarkably, by varying the size of the scatterer, we are able to drive the system to chaotic regime and observe multiple non-Hermitian spectral degeneracies in the billiard spectrum. These non-Hermitian degeneracies imply the existence of exceptional points, which are under intensive theoretical and experimental studies due to the unusual efects on the structure of eigenstates and transport properties of quantum systems. Furthermore, by traversing along closed loops in the parameter space around the exceptional points, we are able to observe a geometrical (Berry) phase resulting from the complex nature of the system's spectrum. To date, non-Hermitian dynamics have only been studied in classical microwave and optical systems. Here we show that exciton polaritons offer a new, highly accessible solid-state platform for fundamental and applied studies of non-Hermitian quantum physics and quantum transport with matter waves.

9668-186, Session PMon

Optomechanically induced chirality in metamaterials

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Previous studies have shown that the direction of the optical force acting on optomechanical structures is determined by the symmetry of the eigen-mode profiles [1-3]; this is the case when the gradient force dominates. However, in metamaterials, gradient and scattering forces coexist, and the latter can be designed to be much larger than the former. More importantly, scattering forces have many degrees of freedom controlled by the incident wave, this allows us to generate an optical force and even control its direction without changing the original structural symmetry. Here, we study a metamaterial composed of a planar zig-zag array of dipole meta-atoms. The meta-atoms have identical geometries but different orientation. We found that nontrivial forces exist when the incident polarization does not coincide with the symmetry axes of the system: the scattering forces acting on the two types of meta-atoms become highly asymmetric or even negative for a particular type of meta-atom. This effect is due to the nontrivial phase response around the antisymmetric mode of the system, which provides a unique actuation mechanism to transform the planar metamaterial into a stereoscopic chiral metamaterial. One possible design is to combine the meta-atoms with flexible nano-beams. Since the direction of forces can be controlled with incident polarization, the handedness of the transformed chiral metamaterial can also be tuned. Our structure also provides a novel route to create a subwavelength opto-acoustic source, with the acoustic frequency controlled by the modulation of the incident polarization.

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9668-187, Session PMon

Pulsatile flow generated by thermoplasmonic Marangoni effect

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Light-induced Marangoni flows generated by a temperature gradient at a gas-liquid interface are gaining much attention for microfluidic devices. These flows can be spatially controlled by changing a position of a laser spot without any mechanical actuators. A recent study reported that rapid vortex flows are induced around a microbubble by irradiating Au nanoparticle arrays with a laser at constant intensity [1]. If we modulate the intensity of the laser, microfluidic flows are expected to be controlled dynamically. In this presentation, we report the pulsating flows induced around a microbubble by irradiating with the sinusoidally intensity-modulated laser. A shallow cell with 50 μm height created on a Au island film was filled with water in which polystyrene spheres were dispersed for visualization. By focusing a laser (wavelength: 785 nm) onto the Au islands, we generated a microbubble and observed the flows around it. When the off-centered part of the microbubble is irradiated with the laser, two symmetric vortex flows were observed. By modulating the laser intensity sinusoidally, the vortex flows pulsated. Depending on laser-modulation frequency, not only the pulsation frequency but also the flow pattern changed significantly. These results are understood in terms that localized photothermal conversion on Au islands induces rapid change in the temperature gradient distribution around the microbubble. This enables the dynamic control of thermoplasmonic Marangoni flows and can be applied to manipulate micro and nanoparticles dispersed in microfluidic devises.

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9668-188, Session PMon

Development of functional nano-particle layer for highly efficient OLED

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Organic light-emitting devices (OLEDs) recently has gathered much attraction for the display application as well as lighting system. However, since OLEDs is composed of many layers considerable loss occurs when passing through the he multi-layer thin film structure. The typical light loss is approximately 80% which means only 20% of light is going through the outside of the device. To solve this problem, optical out-coupling technology is necessary to derive a lot of light from the device. The light extraction technology can be categorized as an internal extraction or an external extraction technique by the position of light extraction structure. In this research, we focused internal extraction technology because it has more merits such as high luminous efficiency y, wide viewing angle and thinner structure.

In this research, we have studied the effect of a functional internal light extraction layer to increase the light extraction efficiency of OLEDs. Metal oxide nano-particle was s mixed with polymer matrix to form the well-dispersed nano-particle layer on the glass substrate first. The light scattering effect of this nano-particle layer r can increase the light efficiency of OLEDs by changing the optical path of light which normally go outside of the device due to wave guide effect or total internal reflection. Several nanoparticle and polymer matrix were adopted to make a functional nanoparticle layer and they showed good scattering properties which results in the high efficiency of OLED structure.

9668-189, Session PMon

Plasmonic nano-emitter using four-wave mixing (FWM)

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Nobel metals exhibit exceptionally large optical nonlinearity upon the excitation of plasmons, rendering them promising media for multiwavelength emitter at nano scale. Of particular interest, gold possesses plamonic resonance in visible and is chemically inert which make gold the best candidate for bio-molecular sensing combining the locally enhanced electromagnetic fields. In this study, we demonstrate a nano-emitter where the emitting wavelength and polarization state are potentially tunable which may readily be used to identify the chirality of bio-molecules.

Gold nano trimer was prepared by drop coating technique where 10 μl of monodispersed gold solution (0.0254 mM, 100 nm in diameter) was dropped and dried out on the glass substrate at ambient temperature. Controllable four-wave mixing (FWM) was produced at gap sites where plasmon hybridization occurs when the transform-limited pump overlapped with the linearly chirped supercontinuum probe spatio-temperally. By varying the relative time delay and the polarization states between the pump and probe beams, the emission wavelength of the FWM as well as the polarization state can be manipulated at one's desire. As expected, when the pump and probe beams are cross polarized, the output FWM exhibits elliptical polarization with an extinction ratio of 2.31. Since flat sample only produces linear polarized FWM, we conclude that the elliptical polarization is generated by the retardation effect during the plasmon gap mode hybridization process of the trimer. Detail the mechanism may benefit the manipulation of the output beam which is substantial for creating nano-emitters for the identification of chiral molecules.

9668-190, Session PMon

Robust high-coupling efficiency inverse taper coupler for silicon waveguide

Peng Wang, Aron W. Michael, Chee Yee Kwok, Ssu-Han Chen, The Univ. of New South Wales (Australia)

Inverse taper is an important and common technique used for coupling light from a fiber to a submicron silicon waveguide. However, it suffers from significant coupling loss when rough interface surface and misalignment between fiber and waveguide exist. As a result, it requires mechanical polishing or complex facet etch and expensive active precise alignment setups involving infrared optical microscope. And therefore makes it feasible only with sufficient equipment support and complicated fabrication process.

This paper presents an inverse taper coupler with passive alignment structure that does not require mechanical polishing or expensive alignment setups. The coupler has a 240nm thick silicon waveguide that is linearly tapered down from 500nm to 160nm in a length of 28um on top of 3um thick oxide box. The silicon waveguide is covered by a 3um thick PECVD SiO_2 cladding on top. The top and bottom cladding SiO_2 layers are etched to form a 6um wide and 50μm long cladding with the silicon taper waveguide in the middle, a 10um long and 6μm wide SiO_2 waveguide core from the end of the taper, and 174μm wide trench opening to the silicon substrate. The silicon substrate in the trench, underneath the SiO_2 cladding and waveguide core are removed by TMAH wet etch to form a V- groove for fiber insertion and precise passive alignment. Beam from the fiber is coupled into the SiO_2 waveguide core first and then into the silicon waveguide taper. The result shows that the coupling loss of this new approach is 3.3dB include the interface loss, and a ± 2um misalignment tolerance is up to 1.2dB in both horizontal and vertical direction. In comparison to previously reported inverse taper arrangements, the proposed approach has demonstrated significantly improved coupling efficiency and misalignment tolerance.

9668-191, Session PMon

Design and simulation of piezoelectric PZT micro-actuators with integrated piezoresistive displacement sensors for micro-optics applications

Ssu-Han Chen, Aron W. Michael, Chee Yee Kwok, Peng Wang, The Univ. of New South Wales (Australia)

Precise movement of a micro-lens in the out-of-plane direction is a desirable function in many Micro-Opto-Electro-Mechanical Systems such as miniaturized confocal microscopy, pico-cameras and pico-projectors. The actuation mechanisms that have been used for such applications are so far based on electro-thermal, electro-static actuation and electro-magnetic. Due to requirements such as large out-of-plane deflection, high resonance frequency, low power consumption, low driving voltage and demand for further miniaturization of such device, piezoelectric driving mechanism based on thin films is considered to be an attractive and promising approach. To such end, we have designed, fabricated and tested a novel piezo-electric actuator that can fulfill these requirements. However, the precise positioning of the actuator is affected by hysteresis and creep effects of the piezo-electric film. Moreover, the dynamic response of the actuator can be enhanced by implementing a control mechanism. In order to achieve these, on-chip displacement sensor should be integrated with the actuators. In this paper, we are presenting the design, simulation, and modeling of the novel piezoelectric actuator integrated with on-chip piezo-resistive sensors. COMSOL Multiphysics is used to perform and facilitate the design, simulation and modeling. The actuator consists of eight unimorph piezoelectric actuators symmetrically attached to a lens holding frame through connecting beams at one end, and to the silicon substrate at the other end. The piezoelectric actuators consists of multilayer structure operate at d13 mode. In-situ doped E-beam evaporated polysilicon thin-films are embedded in-between the structural layer and the PZT thin film at the supporting end of the actuators as sensors. The residual stress in the various films and fabrication induced imperfections have been taken into account in modeling and simulation. The integrated system has resonance

frequency of 2.4KHz before lens integration and 0.75KHz when loaded with 300μg mass as mico-lens, Results shows 0.5μm/V displacement sensitivity and piezoresistive sensitivity of 0.43mV/V/MPa are obtainable. Displacement resolution of better than 100nm can easily be measured without using signal processing.

9668-192, Session PMon

Surface plasmon interference lithography using Al grating structure on glass

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Photolithography is used to the important technologies of the device fabrication process in the semiconductor industry. However, photolithography has the pattern resolution limit because of the diffraction of light. Surface plasmon (SP) is one of the ways to overcome this limit and that is a recently proposed nanolithography technology. In order to use SP, we make the fabrication process using a Al grating structure on glass (glass/Al grating/PR structure). The perfect contact of photoresist and Al grating is increased the effects of SP because the contact gap is reduced in the photolithography process. The expected patterns pitch is 120 nm (simulation results) and 115 nm (fabrication results). Fabrication result of surface plasmon interference lithography (SPIL) is possible to use SP in photolithography area. Furthermore, the fabrication results analyze irregular patterns with the shape of random horizontal patterns, and it is found that the patterns result from the Al line edge roughness. Therefore, other techniques to reduce the Al line edge roughness could enable clearer Al line patterns in SPIL.

9668-193, Session PMon

Effect of photonic structures on the optical properties of nano-phosphor

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The modernization of the society is based on the fabrication of the technologically important materials in the laboratory for the different applications. Optical materials and photonic structures based on rare earth elements attracted the attention of the researchers to develop new devices, new theories for the advancement in the area of technology. Photonic crystals are artificial structures which require periodicity in dielectric constant or refractive index on a sub micrometer scale [1-2]. They are optical analogue to crystalline solid. In crystalline solid there is an infinite repetition of a unit cell, which consists of atoms or molecules with corresponding symmetry elements. Therefore, a crystal represents a periodic atomic potential to control the flow of electrons, whereas in photonic crystal periodic variation in dielectric constant to control the propagation of light.

We synthesize the PMMA microspheres using colloidal crystallization method. PMMA photonic crystals were developed by self assembly vertical deposition method. Developed templates were infiltrated with phosphors and their inverse photonic structures have been obtained by annealing at 500o C temperature. The role of the phosphor photonic structure on the optical properties has been studied and compared with its powder form.

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9668-194, Session PMon

Performance limits of stimulated Brillouin scattering due to nonlinear loss

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Stimulated Brillouin Scattering (SBS) is a third-order self-amplifying nonlinear interaction between light and a hypersonic acoustic wave in matter and similar to Raman-scattering. It is employed in fibre optics for numerous applications such as sensing, pulse generation and microwave photonics and has become one of the driving forces in the study of on-chip opto-mechanics. Therefore, recent SBS research has focused on silicon photonics. However, silicon as a waveguide material exhibits significant nonlinear loss. While the trade-off between desired nonlinear effects and losses is well studied for conventional third-order nonlinearities, a corresponding investigation of SBS and nonlinear loss has been missing.

We present our findings on the interplay of SBS, linear loss, two-photon absorption and nonlinear free carrier absorption. From a coupled-mode description we derive upper bounds for power handling, output power and total signal amplification along the whole waveguide. We furthermore derive a natural figure of merit for waveguides involving all three loss mechanisms and provide expressions that relate the SBS-performance to this simple number. Unlike the Kerr-effect, SBS is not tied to the nonlinear loss coefficients via the Kramers-Kronig relations, but generally follows the linear permittivity. Therefore, a wide range of figures of merit can be realised by appropriate choice of materials and operational wavelength. In the context of silicon photonics, we find that the SBS-performance improves dramatically in the mid-infrared range beyond 2200nm.

9668-195, Session PMon

Effect of CNT addition on the energy release during the thermite reaction

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Nano thermites consist of a metal as fuel and a metal oxide as an oxidizer, with particle size in nanometer range. The contact between the fuel and oxidizer is intimate in case of nano particles instead of micro particles. The increase in specific surface area at nano scale allows more reaction locations and enhances heat transfer rate thereby incerasing the heat of reaction or the energy release rate compared to the conventional microscale energetic materials. Nano size of the particles tends to decrease the mass transport wheras the agglomatarion of the nano particles increases the mass transport thereby affecting the rate of energy release. The agglomaration and re-agglomeration of the particles can be minimised by incorporating carbon nano tubes using suitable synthesis technique.

In the present study the CNT added Al/Fe2O3 thermite is synthesized by physical mixing method having CNT wt% varying from 1% to 5% in the step of 1%. The structure of the thermite is analysized using XRD, SEM, Raman and TEM characterization techniques. The role of CNT in minimizing the re-agglomeration of nano particles of the thermite constituents is authenticated by the structural stuidies. Differential scanning calorimetry is performed for the synthesized samples to observe the effect of CNT addition on the enthalpy of exothermic thermite reaction. The heat of thermite reaction is found to increase with the increase in the CNT weight precent in the thermite samples.

9668-196, Session PMon

Preparation and imaging performance of nanoparticulated LuPO4:Eu semitransparent films under x-ray radiation

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The aim of the the present work was to demonstrated the fabrication technique for semitransparent layers of nanoparticulated (~50 nm) LuPO4:Eu phosphor with two different Eu concentration (5 and 15%). Furthermore to present their basic luminescent properties and provide results for their performance in a planar imaging system incorporating a CMOS photodetector. For comparison purposes, the imaging performance of a Gd2O2S:Eu phosphor screen, prepared by sedimentation is also shown. Parameters such as the Detective Quantum Efficiency (DQE), the Noise Power Spectrum (NPS) and the Modulation Transfer Function (MTF), were investigated.

Low frequency DQE values of the 460 ?m and the 220 ?m LuPO4:Eu films were comparable and even higher than those of the 91 ?m Gd2O2S:Eu screen, while for higher frequencies DQE values are clearly higher for the Gd2O2S:Eu screen. The combination of the higher MTF of this screen, compared with the aforementioned LuPO4:Eu films, and the good noise properties result in higher image quality, for frequencies 2 to 10 cy/mm. On the other hand, comparing this screen with the thinner LuPO4:Eu films, the better noise properties, arising from the higher luminescence efficiency, provides better overall image quality to Gd2O2S:Eu screen.

The LuPO4:Eu semitransparent films seems to be a very promising scintillator for stationery X-ray imaging. The acquired data allow to predict that high-temperature sintering of our films under pressure may help to improve their imaging quality, since such a processing should increase the luminescence efficiency without significant growth of the grains, and thus without sacrificing their translucent character.

9668-197, Session PMon

Micromotility measurements of breast cancer cells in a 3D environment with digital holographic microscopy

Chia-Chi Chien, Univ. of South Australia (Australia); Pierre Baganinchi, The Univ. of Edinburgh (United Kingdom); Tianqing Liu, QIMR Berghofer Medical Research Institute (Australia); Benjamin Thierry, Univ. of South Australia (Australia)

Understanding the molecular and physical clues that govern cancer cell motility and more generally their abilities to invade nearby tissues is paramount towards understanding the metastatic process. While 2D studies have provided some important insights, they failed to mimic the complexity of the 3D tumour environment. On the other hand, current technology remains limited in the imaging of cells in true 3D environments.

Towards better understanding of the effects of the molecular and physical 3D environment, we demonstrate the feasibility of non-invasive and label-free motility measurements using digital holographic microscopy (DHM). To this end, a highly metastatic variant of human breast MDA-MB-231 carcinoma cells (MDA-MB-231HM) was used and compared to standard MDA-MB-231 cells in both 2D and 3D environments.

We recorded the phase of MDA MB-231 and MDA MB-231HM cells embedded in matrigel with a digital holographic microscope (Lyncee Tec). Holograms were collected at 250ms interval for 5min. First each cells of the digital hologram was segmented by image processing techniques. Then, we applied a suite of integrated metrics to establish a micromotility profile for each cells such as mean squared phase-average and instantaneous displacements, phase fluctuations, long term correlations and micromotion index. We found clear difference between the two cell lines in their micromotility profile in both 2D and 3D environment, demonstrating for the first time that DHM could correlate cell line aggressiveness with micromotility.

9668-198, Session PMon

Comparison of sensor structures for the signal amplification of surface plasmon resonance immunoassay using enzyme precipitation

Chih-Tsung Yang, Benjamin Thierry, Ian Wark Research Institute (Australia) and Univ. of South Australia (Australia)

Surface plasmon resonance (SPR) biosensing has been successfully applied for the label-free detection of a broad range of bioanalytes ranging from bacteria, cell, exosome, protein and nucleic acids. When it comes to the detection of small molecules or analytes found at low concentration, amplification schemes are desirable to enhance binding signals and turn increase sensitivity. A number of SPR signal amplification schemes have been developed and validated; however, little effort has been devoted to understanding the effect of the SPR sensor structures on the amplification of binding signals and therefore on the overall sensing performance. The physical phenomenon of long-range SPR (LRSPR) relies on the propagation of coupled surface plasmonic waves on the opposite sides of a nanoscale-thick noble metal film suspended between two dielectrics with similar refractive indices. Importantly, as compared with commonly used conventional SPR (cSPR), LRSPR is not only characterized by a longer penetration depth of the plasmonic waves in the analyzed medium but also by a greater sensitivity to refractive index changes.

In this work, an immunoassay platform using horseradish peroxidase (HRP) catalyzed precipitation was utilized to investigate the sensing performance with regards to cSPR and LRSPR. The sensors were functionalized with a capture antibody for the detection of the corresponding HRP conjugated antigen. The enzymatic precipitation of 3,3'-diaminobenzidine tetrahydrochloride (DAB)/H2O2 was then used to amplify SPR signals. The structure-function relationship of cSPR and LRSPR sensors will be presented for both standard refractometric measurements and the enzymatic precipitation scheme.

9668-199, Session PMon

Wideband photonic RF Hilbert transformer using a frequency comb source based on a microring resonator

Thach Nguyen, Mehrdad Shoeiby, RMIT Univ. (Australia); Sai Tak Chu, City Univ. of Hong Kong (Hong Kong, China); Roberto Morandotti, Institut National de la Recherche Scientifique (Canada); Arnan Mitchell, David J. Moss, RMIT Univ. (Australia)

Accessing to both the amplitude and phase of the analogue RF signal over a wide bandwidth is critical important in many applications including radar, measurement and imaging. The phase of an analogue wave form can be obtained from a Hilbert transformer. The performance of electronic implementations of Hilbert transform is limited by large amplitude and phase ripple and very difficult to extend over a broad bandwidth. Photonic RF Hilbert transformers based on multi-tap transversal filtering scheme can have very wide bandwidth with low amplitude and phase ripples provided a larger number of high quality filter taps can be achieved. Multiple discrete laser diodes were used to realize filter taps in previous demonstrations of transversal filtering based photonic RF Hilbert transform, resulting in limited bandwidth. In this presentation, we will report a wideband photonic RF Hilbert transformer based on transversal filtering using an integrated optical frequency comb source in order to realize multi-tap filtering. The comb source is based on Kerr effect on a high quality factor, highly nonlinear microring resonator fabricated from a CMOS compatible,

high-index contrast, doped silica glass platform. The integrated comb source has a wide spectral range with a large frequency spacing of 200 GHz, allowing a large number of high quality filter taps to be realized. A filter with up to 20 taps was demonstrated, showing a 3 dB bandwidth over 5 octaves from 0.3 GHz to 16.9 GHz with almost frequency independent phase response over the pass band. It is difficult to match this performance with electronic or other photonic techniques.

9668-200, Session PMon

Polarization-dependent optical switching based on waveguide-coupled electron-phonon dynamics

Yimeng Wang, Xinping Zhang, Beijing Univ. of Technology (China)

Considering that TE polarization corresponds to pure excitation of waveguide resonance mode and TM corresponds to the excitation of both plasmon- and waveguide-resonance modes, tuning the polarization of the light induces a mixed mode sensitive to the modulation on both the resonant processes.

9668-202, Session PMon

High-throughput poration of mammalian cells using femtosecond laser-activated plasmonic substrates

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We use femtosecond laser-excited plasmonic micropyramids to deliver molecules to living cells with high efficiency, viability and throughput. Our micropyramids produce a strong plasmonic effect under laser illumination by focusing energy in a small volume at the tip of each pyramid. This leads to the formation of microbubbles which temporarily porate the cell membrane and allow dye molecules and siRNA to diffuse into the cytoplasm. We fabricate large-area micropyramid arrays using photolithograpy, anisotropic etching of silicon, metal deposition, and template stripping. We optimize our laser parameters for high efficiency delivery of molecules (>80%) at high cell viability (>90%) for different cell lines, and use flow cytometry to study a large number of cells. Our scalable technique offers an innovative approach to delivering molecules to living cells for applications in regenerative medicine.

9668-203, Session PMon

Development of myoelectric control type speaking valve with low flow resistance

Katsutoshi Ooe, Kohei Sakurai, Shinya Mimaki, Daiichi Institute of Technology (Japan)

We aimed to develop welfare devices for patients with phonation disorder. One of these devices is the electrical control-type speaking valve system. The conventional speaking valves have one-way valve architecture, they open when the user breathes in, and they close when user breathes out and produce voices. This type is very simple and tough, but some users feel closeness in case of exhalation without phonation. This problem is caused by its mechanism what can not be controlled by user's will. Therefore, we proposed an electrical control-type speaking valve system to resolve this problem. This valve is controlled by neck myoelectric signal of sternohyoid muscle. From our previous report, it was clarified that this valve had better performance about easy-to-breath. Furthermore, we proposed the compact myoelectric control-type speaking valve system. The new-type speaking valve was enough small to attach the human body, and its opening area is larger than that of conventional one. Additionally, we described the improvement of flow channel shape by using of FEM analysis. According to the result of the analysis, it was clarified that the shape-improved speaking valve gets the low flow resistance channel in case of inspiration. In this report, we tried to make the flow resistance lower by the shape of current plates, in case of both inspiration and exhalation. From the result of FEM analysis, our speaking valve could get better flow channel than older one.

9668-204, Session PMon

Assessment of bacterial concentrations using an all-fibre fluorometer

Cushla McGoverin, Rachel Guo, The Univ. of Auckland (New Zealand); Scott Choi, Craig Tuffnell, Veritide Ltd. (New Zealand); Simon Swift, Frédérique Vanholsbeeck, The Univ. of Auckland (New Zealand)

Current assessment of the microbiological safety of food products is time consuming and retrospective. Samples taken from food products are cultured on nutrient plates and the bacterial colonies that grow are counted. We are developing a user-friendly method for near real-time quantification of bacterial load within a factory setting.

SYTO 9 is a fluorescent nucleic acid binding staining that is routinely used to examine cells in fluorescence microscopy and flow cytometry. We have been investigating SYTO 9 for the quantitative determination of bacterial content within solutions. In this method we are using an all-fibre spectroscopic system that consists of a 473 nm solid state laser, a DAQ controlled shutter, a 2x2 coupler, a photodiode, 495 nm long pass filter and a spectrometer for fluorescence detection. The shutter ensures the sample is only illuminated when data is recorded and the photodiode enables laser power to be monitored throughout spectral data collection.

The emission spectrum of SYTO 9 stained bacteria consists of a peak at 509 nm with a shoulder at 529 nm, which are due to SYTO 9 bound to DNA and RNA respectively. We have characterised the intensity of these peaks with respect to bacterial concentration, sample preparation and bacterial species. Removal of unbound SYTO 9 from dyed bacterial solutions is important as the fluorescence of the unbound dye may obscure the DNA and RNA signals. Preliminary results show how our technique, with careful sample preparation, can be used to assess bacterial concentration within solution in near real time.

9668-205, Session PMon

Extraordinary optical transmission sensor for measuring LDL cholesterol concentration

Hyerin Song, Kyujung Kim, Pusan National Univ. (Korea, Republic of)

Plasmon based extraordinary optical transmission (EOT) sensor using specific nanoapetures was investigated to enhance sensitivity of biosensor. To find out the optimum nanostructures of EOT, we calculated plasmonic EOT fields distributions formed through the nanoapertures and estimated sensitivity enhancements using those nanoapertures. Optimum nanoapetures were fabricated using electron beam lithography. Consequently, we applied the double aperture array of EOT sensors to measure the concentrations of blood glucose which elevates viscosity of blood vessel. We find the feasibility of EOT biosensors using specific double nanoaperture arrays to efficiently measure the blood glucose with high sensitivity.

9668-206, Session PMon

Intermediate band dye sensitised solar cells

Andrew Nattestad, Univ. of Wollongong (Australia)

As a third generation PV concept, intermediate band (IB) solar cells offer the prospect of higher device efficiencies, increasing light harvesting and hence photocurrent densities, while having minimal impact upon the device operating voltage. Here we report a novel mechanism, based on Triplet-Triplet Annihilation, demonstrating IB behavior under low (< 1 sun) illumination intensities in a Dye-sensitized Solar Cell (DSC) device. The nature of the IB mechanism is further investigated through transient absorption spectroscopy, demonstrating how low energy photons contribute to photocurrent generation. This represents both a significant development for IB technologies as well as a pathway towards higher DSC device efficiencies.

9668-207, Session PMon

Localized surface plasmon resonance biosensor using gold-silver alloy

Heesang Ahn, Kyujung Kim, Pusan National Univ. (Korea, Republic of)

Silver is well known for providing the sharpest SPR peak among many kinds of metals for surface plasmon resonance (SPR) sensor and has enhanced sensitivity to refractive index variation of the sample. For that reason, silver has been widely used for sensitive measurement of surface plasmon resonance (SPR) sensor. However, gold is used instead of silver for the biosensor as gold shows stable optical and chemical properties and has high biocompatibility. Nevertheless, still the sensitivity of the gold substrate is lower than of the silver substrate, so demands for high sensitivity of SPR biosensor exist. In this paper, we fabricated silver-gold alloy film to enhance the sensitivity of the SPR biosensor. Diverse proportions of the silver-gold alloy film were fabricated by evaporation of two sources at the same time. The proportions of the components, gold and silver, were monitored by EDS analysis. Then, SPR peak was practically measured on those silver-gold alloy films to confirm the effectiveness, and eventually find out the optimum ratio of gold and silver. Finally, biocompatibility tests were conducted using cell culture and cell counting analysis.

9668-208, Session PMon

Luminescent solar concentrator improvement by stimulated emission

Md Rejvi Kaysir, Simon Fleming, The Univ. of Sydney (Australia); Rowan W. MacQueen, Timothy W. Schmidt, The Univ. of New South Wales (Australia); Alexander Argyros, The Univ. of Sydney (Australia)

Luminescent solar concentrators (LSCs) based on dyes are an emerging technology that aims primarily to reduce the cost of solar energy, with great potential for building integrated photovoltaic (PV) structures. However, achieving LSCs with commercially viable efficiency is currently hindered by reabsorption losses. Here, we introduce an approach to reducing reabsorption as well as improving directional emission in LSCs by using stimulated emission. Light from a seed laser (potentially an inexpensive laser diode) passes through the entire length of the LSC panel, modifying the emission spectrum of excited dye molecules such that it is spectrally narrower, at wavelengths that minimize reabsorption, and directed by the seed laser towards a small target PV cell which can have an area comparable to the cross section area of the seed source. A fraction of the PV cell's output electrical power is fed back to drive the seed laser, so that additional power into this system is unnecessary. A mathematical model of this system is presented which identifies different physical parameters on the power conversion efficiency and gives the net effective output power from such a system. This model also facilitates a description of the net extracted power from the system and finally sets a minimum condition to drive the seed laser from the output of the PV cell. This information provides necessary steps for designing and optimizing different parameters for the realization of such a device. Some preliminary results with common luminescent dyes will be presented in the conference.

9668-209, Session PMon

Investigation of emission properties of vacuum diodes with nanodiamond-graphite emitters

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Emission properties of vacuum diodes with nanodiamond-graphite emitters were investigated. The nanodiamond-graphite layers deposition were carried out from ethanol vapor at low pressure using microwave plasma.

Three series of experiments were conducted. Researching of emission currents with flat cathodes on silicon wafer coated nanodiamond-graphite layer thickness of 0.1 to 0.3 ?m were done in first series of experiments. In the second series of experiments, the cathode is a silicon wafer covered with a SiO2 layer of 1.0 ?m with vias. Diameter of vias are 2.0 ?m with a pitch of 10 ?m. Nanodiamond-graphite emitters with thickness of 0.1 to 0.3 ?m were formed within the openings on the silicon. In the third series of experiments, the cathode is a silicon wafer, coated the SiO2 layer with thickness of 1.0 ?m. Vias with diameter of 2.0 ?m were formed in nanodiamond-graphite and SiO2 layers. Side wet etching was performed for SiO2 layer under nanodiamond-graphite layer. In this structure projection of nanodiamond-graphite layer was more than 2.0 ?m.

Vacuum emission studies were done at temperature 300K and pressure 1 ? 10-6 Torr. The anode is placed at a distance of 1 to 30 ?m from the cathode.

Threshold voltage from 10-50V per micron and current density about 0.2 A/cm2 were obtained in the first series of experiments. In the second and third series of experiments, a threshold voltage from 1 to 10V per micron and current density more than 2 A/cm2 were displayed. The greatest current density was obtained using a blade-type emitter.

9668-213, Session PMon

Near-field optical microscopy technique for visualising the evanescent fields of silicon photonic and hybrid integrated photonic waveguides using a standard atomic force microscope

Steffen Schoenhardt, RMIT University (Australia); Jonas Dalke, Karlsruhe University of Applied Sciences (Germany); Thach Nguyen, Arnan Mitchell, RMIT University (Australia)

Scanning Near Field Optical Microscopy (SNOM) has been conceived as a means to overcome Abbes diffraction limit, driven by the wish of better understanding the behaviour of optical devices with features in the sub-micron regime, (e.g. photonic crystal structures). Several varieties of SNOM visualisation technique exist: aperture based SNOM has limited lateral resolution due to the size of the extruded fibres used as a scanning tip. Scattering based SNOM offers improved resolution by utilizing an atomically sharp AFM tip as a scatterer, but usually have a poor Signal-to-Noise ratio because of the far-field light collection. Recently, the technique of transmission-based SNOM has become popular as it combines the possibility of using high-resolution AFM measurement techniques to provide highest resolution imaging while showing an excellent signal-to-noise ratio by measuring the signal transmitted through the photonic structure itself [1].

We report on the use of this method to characterize the evanescent field amplitude along a range of SOI dielectric and hybrid plasmonic waveguide structures. We show that by measuring the transmitted and reflected intensities while perturbing the propagation of a wave

in a SOI waveguide structure with an AFM tip, information about the phase and phase velocity can be accessed. This method also enables visualisation of the evanescent field profile at the nanometre scale. The implementation utilises a standard, unmodified AFM along with a standard, packaged SOI device, making this technique accessible to a wide user base, as no further special equipment is necessary for realization of this measurement setup.

9668-214, Session PMon

Hollow silicon microneedle array based trans-epidermal antiemetic patch for efficient management of chemotherapy induced nausea and vomiting

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Chemotherapy Induced Nausea and Vomiting (CINV) is a serious health concern in the treatment of cancer patients. Conventional routes for administering anti-emetics (i.e. oral and parenteral) have several drawbacks such as painful injections, poor patient compliance, dependence on skilled personnel, non-affordability to majority of population (parenteral), lack of programmability and suboptimal bioavailability (oral).

Hence, we have developed a trans-epidermal antiemetic drug delivery patch using out-of-plane hollow silicon microneedle array. Microneedles are pointed micron-scale structures that pierce the epidermal layer of skin to reach dermal blood vessels and can directly release the drug in their vicinity. They are painless by virtue of avoiding significant contact with dermal sensory nerve endings. This alternate approach gives same pharmacodynamic effects as parenteral route at a sparse drug-dose, hence has negligible side-effects and improved patient compliance.

Microneedle design attributes were derived by systematic study of human skin anatomy, natural micron-size structures like wasp-sting and cactus-spine and multi-physics simulations. We used deep reactive ion etching with Bosch process and optimized recipe of gases to fabricate high-aspect-ratio hollow silicon microneedle array. Finally, microneedle array and polydimethylsiloxane drug reservoir were assembled to make finished anti-emetic patch.

We assessed microneedles mechanical stability, physico-chemical properties and performed in-vitro, ex-vivo and in-vivo studies. These studies established functional efficacy of the device in trans-epidermal delivery of anti-emetics, its programmability, ease of use and biosafety.

Thus, out-of-plane hollow silicon microneedle array trans-epidermal antiemetic patch is a promising strategy for painless and effective management of CINV at low cost in mainstream healthcare.

9668-215, Session PMon

Ultrafast generation, transport and relaxation of non-equilibrium carriers in plasmonic nanostructures

Prineha Narang, California Institute of Technology (United States) and Northrop Grumman (United States); Ravishankar Sundararaman, William A. Goddard III, Harry A. Atwater, California Institute of Technology (United States)

Decay of surface plasmons to hot carriers is a new direction that has attracted considerable fundamental and application interest, yet a theoretical understanding of ultrafast plasmon decay processes and the underlying microscopic mechanisms remain incomplete. Recently we analyzed the quantum decay of surface plasmon polaritons and found that the prompt distribution of generated carriers is extremely sensitive to the energy band structure of the plasmonic material. A theoretical understanding of plasmon-driven hot carrier generation and relaxation dynamics from femtosecond to picosecond timescales is presented here. Employing a Feynman diagram approach has been critical to determine the relevant processes. We report the first ab initio calculations of phonon-assisted optical excitations in metals, which are critical to bridging the frequency range between resistive losses at low frequencies and direct interband transitions at high frequencies. Previously a challenge in such calculations of metals has been to treat the intermediate virtual state as well as the energy conserving `on-shell' intermediate states that correspond to sequential processes. Here we compare the plasmon linewidth and decay rates estimated directly from the experimentally-measured complex dielectric functions with theoretical predictions for cumulative contributions from direct, surface-assisted, phonon-assisted transitions and resistive losses.

9668-216, Session PMon

Quantum plasmonics for next-generation optical and sensing technologies

Modjtaba Moaied, The Univ. of Sydney (Australia) and Commonwealth Scientific and Industrial Research Organization (CSIRO) (Australia); Kostya Ostrikov, The Univ. of Sydney (Australia) and Commonwealth Scientific and Industrial Research Organisation (Australia) and Queensland Univ. of Technology (Australia); Mario Silveirinha, Univ. de Coimbra (Portugal)

Classical plasmonics has mostly focused on structures characterized by large dimension, for which the quantum-mechanical effects have nearly no impact. However, recent advances in technology, especially on miniaturized plasmonics devices at nanoscale, have made it possible to imagine experimental applications of plasmons where the quantum nature of free charge carriers play an important role. Therefore, it is necessary to use quantum mechanics to model the transport of charge carriers in metallic nanostructures. Here, a nonlocal quantum model of permittivity is presented by applying the Wigner equation with collision term in the kinetic theory of metals where the dominant electron scattering mechanism is the electron-lattice collisions. The surface plasmon resonances of single silver nanoparticles are investigated using the nonlocal quantum permittivity and the dispersion relation, damping rate, and decay length of surface plasmons are obtained in both infinite and finite spherical quantum well. In nanoparticles with the various sizes from sub-nanometre to atomic scale, the spatial localization of the electron wave function is extended well beyond the average inter-particle distance, when the electrons are sufficiently hot (i.e., around 1 eV). Interesting effects such as warm dense matter and partial lattice disassembly are induced by electron delocalization and non-equilibrium. The successful application of this theory in quantum plasmonics structures such as surface plasmon polariton waveguides, doped semiconductors, graphene, the metamaterials composed of alternating layers of metal and dielectric, and the quantum droplets is anticipated.

9668-218, Session PMon

Measurement of nonlinear properties for PEI tetra sulfonated indium phthalocyanine compounds self-assembly film using improved Tophat z-scan technique

Qing Chang, Heilongjiang Univ. (China); Da-jun Liu, Changchun Univ. of Science and Technology (China); Xinzhi Wu, Junyi Yang, Yinglin Song, Suzhou Univ. of Science and Technology (China)

The nonlinear refraction and absorption properties of a PEI (phthalocyanine indium) tetrasulphonated chlorinated phthalocyanine electrostatic self-assembled film were studied using a simple and high sensitivity technique. We adopted picosecond laser pulses as source light and modified top-hat Zscan technique with a disk and a small aperture to explore the nonlinear refraction of the film. Experimental results show that the measuring sensitivity is increased by two orders

of magnitude. Through theoretical fitting, we obtain the nonlinear refraction index and nonlinear absorption coefficients of the film are 2.1?10-14 m2/W and 2.4?10-7 m/W, respectively.

9668-501, Session Plen

3D fabrication nano to macroscopic: why we need that!

Gordon G. Wallace, Univ. of Wollongong (Australia)

It is time to celebrate the demise of the conventional approach to making stuff wherein the realisation of practical devices was in many ways restricted to the use of materials amenable to mass production using capital intensive facilities.

Over the past three decades we have amassed a stock pile of new materials not amenable to this approach. These new materials have properties that can help us tackle big issues in areas such as energy and health. Particularly in the latter area the need for customised structures is critical.

In both areas nature suggests that hierarchical structures wherein nano and microscopic features are distributed throughout a macroscopic structure are required for optimal performance.

Here we will use the example of the discovery of new organic conductors to highlight the opportunities and the challenges. We will show how advances in 3D printing as well as knitting and braiding of fibers have enabled the fabrication of new devices. We will report on progress towards the development of protocols that enable 3D assembly across the nano to macroscopic domains.

9668-52, Session 3A

Recent progress in semiconductor nanowire photodetectors for multispectral imaging and in nanoscale sensing using surface-enhanced Raman spectroscopy *(Invited Paper)*

Kenneth B. Crozier, Harvard School of Engineering and Applied Sciences (Australia)

We present recent studies in which engineering the interaction between light and nanoscale materials has been pursued for applications in image sensors and in spectroscopy. In the first, we investigate germanium nanowires for multispectral imaging. The interaction between a material and light can be controlled by nanostructuring it. Advanced methods for controlling the visible-to-infrared absorption spectra of semiconductor materials would present opportunities for photodetectors with engineered spectral response. Here, we experimentally demonstrate the fabrication of arrays of vertical Ge nanowires with different diameters. Measured reflection spectra show dip features for which electromagnetic simulations predict enhanced absorption. These can be shifted to longer wavelengths by increasing the diameters of the nanowires. In the second study, we review recent work by the author on plasmonic structures for surface-enhanced Raman scattering. We show that quantum mechanical tunneling across the gaps limits the enhancement in SERS. We furthermore demonstrate a micro-patterned silicon structure that enables the preparation of a SERS substrate and pre-concentration of the analyte molecules.

9668-53, Session 3A

Nitrogen acceptors in ZnO nanowires

Cuong Ton-That, Liangchen Zhu, Matthew R. Phillips, Univ. of Technology, Sydney (Australia); Bruce C. C. Cowie, Australian Synchrotron (Australia); Sevak Khachadorian, Sarah Schlichting, Nadja Jankowski, Axel Hoffmann, Technische Univ. Berlin (Germany)

The difficulty to achieve stable p-type ZnO has hindered the development of ZnO-based optoelectronic devices. In this work, nitrogen-doped ZnO nanowires were prepared by annealing in a nitrogen plasma, where the doping level was governed by the plasma time. X-ray absorption near-edge spectroscopy (XANES), cathodoluminescence and photoluminescence spectroscopy were used to investigate the chemical states of nitrogen species incorporated in the nanowires. It was established that plasma annealing produces three N-related defects: NO, free N2 that is loosely bound to the ZnO lattice and (N2)Zn with signature XANES peaks at P1 (400.0 eV), and P2 (400.7 eV) and P3 (404.5 eV), respectively. As the plasma annealing time increases, the P2 component is enhanced relative to P1 and P3, indicating more nitrogen is present as molecular species. The luminescence spectra from the N-doped nanowires consists of a D0X emission at 3.36 eV and a donor-acceptor pair (DAP) emission at 3.232 eV. The DAP emission peak exhibits a blue shift with increasing excitation power and is attributed to shallow molecular N2 acceptor. Following plasma annealing, the DAP intensity increases considerably relative to the D0X. The work establishes a direct link between the DAP emission in ZnO and the concentration of loosely bound N2, and confirms that N2 at Zn site is a potential candidate for producing a shallow acceptor state in ZnO as theoretically predicted by Lambrecht and Boonchun [Phys. Rev. B 87, 195207 (2013)]. Additionally, shallow acceptor states arising from nitrogen-oxygen complexes can be ruled out in this study.

9668-55, Session 3A

Evaluation of zinc oxide tetrapods for biosensor application

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Zinc oxide (ZnO) is a well-known II-VI semiconductor material that has gained increased interest in past decades due to its wide direct band gap (3.4 eV), large exciton binding energy (60 meV) and high electron mobility (200 cm2 V-1 s-1). Owning to these unique properties, ZnO has been used for various applications including biosensor and optoelectronic devices. With control of synthesis conditions, ZnO can be synthesized with different morphologies such as nanospheres, nanotubes and nanowires. Recently ZnO tetrapods (ZnO-TPs) have attracted significant attention due to their unique morphology consisting of four branches joined together. By taking the advantage of multiple electron transfer paths, high chemical stability and biocompatibility, ZnO-TPs is considered as one of the most promising candidates for various biosensing devices.

In this work we report a systematical study on structural, optical and electrochemical properties of ZnO-TPs. The morphology of ZnO-TPs was confirmed by SEM as having four legs of micrometer size. The ZnO-TPs were dispersed in glucose to mimic real biological environment for photoluminescence (PL) characterization. The PL intensity in the UV range increases at initial stage and decreases afterwards, which could be attributed to surface passivation during glucose decomposition. Current-voltage response of ZnO-TPs/Au substrates was investigated by cyclic voltammetry (CV) with various glucose concentrations. Stable signals were detected to confirm the potential of ZnO-TPs for biosensor applications. In addition, graphene is introduced to the ZnO-TPs, which could potentially enhance the sensitivity of the biosensors.

9668-56, Session 3A

2D materials for nano-photonic devices *(Invited Paper)*

Yuerui Lu, The Australian National Univ. (Australia)

Two-dimensional (2D) materials have become very important building blocks for electronic, photonic, and phononic devices. The 2D material family has four key members, including the metallic graphene, transition metal dichalcogenide (TMD) layered semiconductors, semiconducting black phosphorous, and the insulating h-BN. Owing to the strong quantum confinements and defect-free surfaces, these atomically thin

layers have offered us perfect platforms to investigate the interactions among photons, electrons and phonons. The unique interactions in these 2D materials are very important for both scientific research and application engineering. In this talk, I would like to briefly summarize and highlight the key findings, opportunities and challenges in this field. Next, I will introduce/highlight our recent achievements. We demonstrated atomically thin micro-lens and gratings using 2D MoS2, which is the thinnest optical component around the world. These devices are based on our discovery that the elastic light-matter interactions in high-index 2D materials is very strong. Also, I would like to introduce a new two-dimensional material phosphorene. Phosphorene has strongly anisotropic optical response, which creates 1D excitons in a 2D system. The strong confinement in phosphorene also enables the ultra-high trion (charged exciton) binding energies, which have been successfully measured in our experiments. Finally, I will briefly talk about the strong light-matter interactions of 2D materials and their potential applications in energy harvesting.

9668-57, Session 3A

Investigations on the influence of laser wavelength to generate micro texture on ITO coacted polyethylene terephthalate using liquid assisted laser processing for the development of multi-reflective solar cell

Ashish K. Shukla, Iyamperumal A. Palani, M. Anbarasu, Indian Institute of Technology Indore (India)

The recent growth in the development of Solar cells is on Flexible Substrates. The Topic of Surface processing of Polyethylene terephthalate substrate Using focused Nd: YAG Laser beam of Primary, secondary and Third harmonics leading to generation of micro structures grabbed much attention in research community. Several applications of micro structures, including increasing light management by multi-reflective phenomena for the high photovoltaics efficiency. Among applications and various materials micro structures of solid substrates has been extensively researched. Liquid assisted laser processing (LALP) of ITO coated PET Sheet on focal point and on the top of substrate is challenging task. LALP of selective linear and non-linear ablation of amorphous and crystalline nature of substrate up to 100 ?m irregular hillocks is of special interest. Few researchers have tried PET without focusing laser energy at focal point and LALP. They generated through other means of laser, sputtered, plasma and reactive ion etching. In this research work attempt has been made to generate irregular hillocks micro structure on ITO coated PET substrate in pulse, multipass repetition mode using distilled water as a liquid absorber in LALP at focal point of beam. At varied fluences and an optimized pitch of 250 ?m cross and vertical hatch of 450 and 900 is patterned. An investigation is carried out to check the effect of wavelength, mode of pulse, repetition rate, fluences, focal point & absorber liquid on coated substrate. Due to anisotropic behavior of procured substrate, absorption of energy is uncertain.

9668-58, Session 3A

Using light to control the optical, plasmonic, and mechanical properties of stacked azo-containing hybrid micro/nanosystems

Filippo Fabbri, Univ. Paris-Sud 11 (France); Luca Sorelli, Univ. Laval (Canada); Anh-Duc Vu, Ecole Polytechnique (France); Jessy F. Baronet, Univ. Laval (Canada); Khalid Lahlil, Lucio Martinelli, Thierry Gacoin, Yves Lassailly, Jacques Peretti, Ecole Polytechnique (France)

Thin films containing azobenzene derivatives present specific and spectacular photomechanical responses to light stimuli. In particular, when grafted into solid-state matrices, the photo-isomerization of the azobenzene molecules can produce a mechanical deformation of the host matrix, of the order of the film thickness. This allows controlling the formation of 1D/2D patterns with sub-micron feature dimensions on large areas by using simple optical methods. The submicron patterns have specific properties (optical transmission / reflectivity, diffraction, wettability, ...) that can be adjusted by controlling the size and characteristics of the patterns. These structured surfaces can be exploited in various application areas (such as optical components, window functional coatings, smart glasses, holographic recording, etc.).

In this work, we present innovative non-conventional patterning techniques based on the photomechanical properties of azo-materials, that we use to elaborate stacked hybrid gold/dielectric micro/nanostructured systems, whose sub-micron patterns exhibit specific optical and plasmonic properties. By tuning the light stimuli we can optically adjust the size and characteristics of the motifs, hence tuning the structures' properties. The photodeformation processes are quantitatively studied by statistical nanoindentation and by coupled shear-force/SNOM microscopy techniques, which give access to the photodeformation kinetics and to the light field distribution in-situ, in real-time and at nanoscale. Nanoprobes are also used to locally influence the photomechanical processes, thus achieving complex light-assisted nanostructuration. Moreover, these techniques unveil the possibility to optically control the azo-materials' mechanical properties such as plastic and viscoelastic regimes, which can be exploited in innovative coupled top-down/bottom-up fabrication processes.

9668-221, Session 3A

Toroidal response due to strong near-field coupling in planar metamaterials

Alexey Basharin, Foundation for Research and Technology-Hellas (Greece)

No Abstract Available

9668-59, Session 3B

Flexible and highly efficient far-field three-dimensional nonlinear nanofocusing *(Invited Paper)*

Baohua Jia, Swinburne Univ of Technology (Australia)

Flexible and highly efficient ultrathin flat lenses have been long sought indispensable components in nano-optics and on-chip photonic systems. However, it is fundamentally challenging to achieve flat lenses with submicrometer thickness due to the insufficient phase modulation when the thickness of a lens is reduced to a subwavelength scale. On the other hand, most of the current flat lens concepts are based on rigid substrate, therefore it remains difficulty to achieve high mechanically robust with flexible integration capabilities, which significantly limits their wide applications.

In this paper, we developed a flexible, transparent and highly nonlinear graphene oxide (GO) film that is only 200 nm in thickness. By manipulating the tunable local property variations during the laser GO reduction process, new ultrathin flat lens could be designed with capabilities of both amplitude and phase control. As a result, the strong focusing of light has been demonstrated using our GO lens, which is a result of the interferences of wavelets originated in the lens plane. In addition, a large scale GO thin film is integrated on a flexible polydimethylsiloxane (PDMS) substrate. After bending, the GO lenses remain functioning without sacrificing the focusing performance, demonstrating the excellent mechanical strength.

9668-60, Session 3B

Scintillating nanoparticle-photosensitizer conjugates towards x-ray activated photo dynamic therapy (PDT)

Sandhya Clement, Elizabeth Camilleri, Wei Deng, Ewa M. Goldys, Macquarie Univ. (Australia)

The disadvantage of limited light penetration in PDT with visible light sources for exciting the photosensitizer to generate singlet oxygen can be overcome by using X-rays which can penetrate into tissue far beyond light penetration depth. This has been introduced by Chen et al1 who proposed to carry out PDT with X-rays, by conjugating PS molecules to scintillating nanoparticles (ScNps).

In this work we demonstrate singlet oxygen generation from CeF3 -verteporfin conjugates. The CeF3 is a known scintillator with peak emission wavelength matching the absorption of verteporfin (VP), clinically approved photosensitiser for PDT in neovascular macular degeneration. The singlet oxygen generation from VP as well as its conjugate in water at 365 nm has been demonstrated with singlet oxygen sensor green (SOSG) as singlet oxygen detector probe. This is done as a preliminary confirmation of singlet oxygen generation from the photosensitizer itself as well as photosensitizer in the conjugate under its wavelength of absorption. Also singlet oxygen generation from the conjugate under X-ray irradiation was demonstrated. The X-ray singlet oxygen quantum yield of the conjugate has been quantified and also we tried to estimate the singlet oxygen dose which is achievable with CeF3-VP conjugates for deep cancer PDT treatment during standard radiotherapy. This dose values estimated are comparable with the Neidre dose. The results obtained from this work suggests that this nanoscintillator–photosensitizer conjugate has potential scope in nanoscintillator-mediated photo dynamic therapy.

1 Chen, W.; Zhang, J. Journal of nanoscience and nanotechnology 2006, 6, (4), 1159-1166.

9668-61, Session 3B

Some minding about the creation of multi-spectrum passive Terahertz imaging system

Alexander Denisov, Jing hui Qiu, Shengchang Lan, Liu Hao, Harbin Institute of Technology (China)

One of the priority trend in electronics is the design of the imaging system in various spectral band of the electromagnetic waves. Multy-spectrum system is one of the critical technologies. It is principal to direct efforts for the creation multy-spectrum system in single block with simple regulation of the receiving band. First question in this field is to do the receiving pixel with tunable band for the matrix imaging system. Best candidate for this aim is Josephson Junction (JJ). The using of the JJ for this purpose can stay the new trend for the creation modern multy-spectrum passive terahertz imaging system. There proposed some analysis at the base of theoretical and experimental results of the possible noise parameters of the such pixel.

9668-62, Session 3B

Creation of reduced graphene oxide film along core surface of the microstructured fibres for hybrid optoelectronic devices

Yinlan Ruan, The Univ. of Adelaide (Australia); Liyun Ding, Wuhan Univ. of Technology (China); Jingjing Duan, Shizhang Qiao, Heike Ebendorff-Heidepriem, Tanya M. Monro, The Univ. of Adelaide (Australia)

Graphene has ultrahigh carrier mobility and remarkable optical properties, including high transparency, saturable nonlinear absorption and fluorescence quenching [1]. Its integration over a long length of optical fibers will enable a variety of hybrid devices including surface plasmon resonance, optical modulators or detectors. However, it is challenging to directly integrate graphene into long length of the fibres due to difficulty in manipulation of graphene sheets. Graphene oxide (GO) are graphene sheets modified with oxygen functional groups, which results in GO insulating but is well dispersed in water. GO has been recognized as a promising precursor for bulk production of graphene materials. It has very similar optical properties to graphene. Thermal and chemical reduction methods have been used to remove the oxygen-containing groups from the GO to achieve reduced GO (rGO) [2], which is conductive. Here we demonstrated a robust and reproducible method to form rGO films on the core surface of the suspended core fibers through optical trapping by filling the fibers with GO solution and using a picosecond 532nm laser guided in the fibre core. The evanescent field of the micron core fibers led to photothermal reduction of the GO into rGO, which was confirmed by narrower fluorescence bandwidth of the rGO films due to decreased disorder-induced states with sp2 carbon atoms becoming dominant. Creation of the rGO film along the whole fiber length demonstrates a reliable and easily performed method to fabricate conductive and optical materials with high linear and nonlinear refractive index into the fiber platform, and open up possibility to develop hybrid optoelectronic devices in the optical fibers with high efficiency.

9668-64, Session 3B

Study of ellipticity effect on LP11 modes field distribution in a step index fiber

Hong Ji, Yinlan Ruan, Heike Ebendorff-Heidepriem, The Univ. of Adelaide (Australia); Tanya M. Monro, Univ. of South Australia (Australia)

In recent years, doughnut shaped LP11 modes in cylindrical optical fiber have been studied and applied in optical fiber based stimulated emission depletion (STED) microscopy for bio imaging application. In STED microscopy, the high intensity doughnut shaped beam switches off emission of the fluorescent molecules located within the doughnut pattern while those molecules in the central dark hole area still emit fluorescence, leading to a sharp image with nanoscale resolution. The higher intensity of the doughnut pattern, the better resolution can be expected. However, these LP11 modes shape can be easily distorted from an enclosed doughnut shape to a Hermite-Gaussian-like shape due to the asymmetry of the fiber core. The latter has intensity distribution with two lobes. Thus intensity distribution of the doughnut beam is sensitive to the symmetry of the fiber core. It is understood that the fluorescence emissions of the molecules within the doughnut pattern cannot be efficiently depleted with poor uniformity doughnut beam, which will decrease the imaging resolution. In this work, in order to understand the impact of the fiber core asymmetry on uniformity of the doughnut beam intensity distribution, we examined dependence of the doughnut beam intensity distribution on ellipticity of the step index fiber core with air cladding with different refractive indices and core dimensions with finite element numerical simulations. Higher index smaller and core size lead to a better uniformity for doughnut beam with the same core ellipticity. The preliminary results provide information to control the fiber core ellipticity to get an expected uniformity of the doughnut beam for optical fiber based quality STED microscopy application.

9668-65, Session 3B

Gigapixel hyperspectral microscopy for high content analysis

Antony Orth, RMIT Univ. (Australia) and The Rowland Institute (United States); Monica J. Tomaszewski, Richik N. Ghosh, Thermo Fisher Scientific Inc. (United States); Ethan F. Schonbrun, The Rowland Institute at Harvard (United States)

A key part of the drug discovery process relies on image-based assays to assess the efficacy of potential medical compounds. These assays involve imaging up to millions of cells, each at several fluorescent channels, and distilling the information to a tractable number of metrics that describe the cellular response – a process called high content analysis (HCA). Digital microscopy on this scale presents a severe bottleneck, limiting the rate at which potential drugs can be trialed. The most common HCA microscope design is a widefield microscope fitted with a motorized stage and control software. This architecture is inherently slow because the microscope stage has to stop and start at each imaging location to avoid motion blur. We have developed a hyperspectral microlens-based microscope that is purpose-built for imaging the large fields-of-view encountered in HCA. Our microlens microscope resembles a massively parallelized point-scanning confocal microscope, with each microlens operating as

an epifluorescent objective lens. Unlike standard widefield stop-start designs, our microscope acquires data continuously, thus improving pixel throughput. The microscope is capable of acquiring gigapixel image sets with more than 10 spectral channels. We show imaging results of fluorescent beads over multiple wells of a 96-well microplate, and demonstrate linear unmixing of up to 6 independent fluorescent channels. To our knowledge, these are the largest hyperspectral microscopy images reported in the literature to-date. We also use blind spectral unmixing to identify a key cell proliferation marker in HeLa cell cultures - a proof of concept experiment for real world assays.

9668-110, Session 3B

All optically driven nano and micromachines *(Invited Paper)*

Halina Rubinsztein-Dunlop, The Univ. of Queensland (Australia)

Light carries both energy and momentum which can be used to trap and move materials noninvasively at length scales ranging from tens of nanometers to tens of micrometers. These so called Optical Tweezers have provided unprecedented access to physical, chemical and biological processes on a microscale.

Since a light beam can also carry angular momentum (AM) it is possible to use optical tweezers to exert torques to twist or rotate microscopic objects. Spin angular momentum depends on the degree of circular polarisation of the light, and orbital angular momentum depends on the spatial structure of the beam. If either the spin or orbital angular momentum is altered when the trapping beam is scattered by the particle in the trap, an optical torque will result. Further, it is relatively easy to simultaneously measure optically the torque being exerted, without the need for any elaborate calibration procedure. These optical rotators provide fine orientation control and using these techniques, the mechanical properties of cells can be usefully studied. These methods could also easily find applications in biotechnology and micromechanics. We use these methods to align and rotate micro-objects with variety of designs and have demonstrated their use in a number of applications ranging from microviscosity measurements to biocompatible systems.

9668-66, Session 3C

Bringing nanoscale matter to life: electrically tunable metamaterials and metasurfaces for control of absorption, emission and scattering *(Invited Paper)*

Harry A. Atwater Jr., California Institute of Technology (United States)

Progress in understanding resonant subwavelength optical structures has fueled a worldwide explosion of interest in both fundamental processes and nanophotonic devices for imaging, sensing, solar energy conversion and thermal radiation control. For most nanophotonic materials, the optical properties are encoded and fixed permanently into the nanoscale structure at the time of fabrication. Achieving electronic tunability of the optical properties is an emerging opportunity to bring metamaterials and metasurfaces to life as dynamic objects composed of tunable nanoscale resonators and antennas. Gated field effect tuning of the carrier density in conducting oxides and two-dimensional materials enables the optical dispersion of individual structures to be altered from dielectric to plasmonic, yielding active nano-antenna arrays with electrically tunable absorption, radiative emission and scattering properties.

9668-67, Session 3C

Experimental observation of magnetic Fano resonances in all-dielectric quadrumers

Alexander S. Shorokhov, Lomonosov Moscow State Univ. (Russian Federation); Benjamin Hopkins, Katie E. Chong, Dragomir N. Neshev, Duk Yong Choi, The Australian National Univ. (Australia); Maxim R. Shcherbakov, Lomonosov Moscow State Univ. (Russian Federation); Andrey E. Miroshnichenko, The Australian National Univ. (Australia); Andrey A. Fedyanin, Lomonosov Moscow State Univ. (Russian Federation); Yuri S. Kivshar, The Australian National Univ. (Australia)

We investigate the interplay between the collective magnetic response of all-dielectric quadrumers and the individual magnetic responses of their dielectric nanoparticles. Unlike their plasmonic counterparts, all-dielectric nanoparticle oligomers are shown to exhibit multiple dimensions of resonant magnetic responses. They possess a possibility for interference between magnetic responses and thereby able to exhibit Fano resonances that are purely magnetic in nature.

The proposed all-dielectric quadrumers were fabricated by electron-beam lithography and reactive-ion etching technique from a-Si:H film on a SiO_2 substrate. The a-Si:H film was made by using plasma-enhanced chemical vapor deposition, their thicknesses and optical quality were obtained from ellipsometry measurements. The sample represents an array of symmetric clusters of four a-Si:H nanodisks with 100 nm gap between them. The period of quadrumers array varies from 1600 nm till 2000 nm in both lateral directions, the height of nanodisks was 100 nm and the diameter changes from 500 nm till 600 nm, respectively.

Spectroscopy of the linear transmission for different angles of incidence and polarizations of incident light was carried out. Experimental results demonstrate the existence of a magnetic Fano resonance in a silicon nanoparticle quadrumers in the near-IR region. Variations in the size of the particles with the fixed gap between them change the spectral position of the Fano resonance of the quadrumers. The numerical CST simulation shows good agreement with the experiment. These results represent the first example of an optical magnetic-magnetic dipolar Fano resonance in a single all-dielectric metamolecule.

9668-68, Session 3C

Fano resonance in waveguide photonic crystals

Jian Zhang, Xinping Zhang, Beijing Univ. of Technology (China)

Fano-like coupling due to coherent interaction between narrow-band photonic resonance mode and relatively broad-band plasmon resonance in metallic nanostructures has been observed extensively in metallic photonic crystals (MPCs). This process is sensitive to the change in the local environments, which makes the MPCs potential candidates for sensors[1], plasmonic nanoantennas[2], optical switching[3], and surface enhanced Raman scattering spectroscopy.

In this paper, we demonstrate that the broad-band feature can also be excited by different processes, e.g. the diffraction of light in a specified spectral range. Strong diffraction of light induces strong optical extinction, which can be adopted to simulate the plasmon-resonance-induced optical extinction. Thus, Fano-like coupling has been observed in a simple waveguide grating consisting of dielectric materials, which results from the interaction between diffraction-induced optical extinction and the second-order waveguide resonance mode.

[1] Xinping Zhang, et al. Advanced Functional Materials. 21, 4219(2011)

[2] Aimi Abass, et al. Nano Letters. 14, 5555(2014)

[3] Xinping Zhang, et al. Advanced Materials . 20, 4455(2008)

9668-69, Session 3C

Polarization-independent wavefront control with silicon Huygens' metadevices

Katie E. Chong, The Australian National Univ. (Australia); Isabelle Staude, The Australian National Univ. (Australia) and Friedrich-Schiller-Univ. Jena

(Germany); Anthony James, Jason Dominguez, Sheng Liu, Salvatore Campione, Ganapathi S. Subramania, Ting S. Luk, Sandia National Labs. (United States); Manuel Decker, Dragomir N. Neshev, The Australian National Univ. (Australia); Igal Brener, Sandia National Labs. (United States); Yuri S. Kivshar, The Australian National Univ. (Australia)

The recent experimental demonstrations of wavefront control with metasurfaces have suggested a new paradigm of optical devices, leading to an escalated interest in flat functional optical metadevices. However, optical metasurfaces face challenges in reaching high efficiencies because of the intrinsic loss of metals at optical frequencies, reflection losses and undesired polarization conversion. Here, we experimentally demonstrate a Gaussian-to-vortex beam-shaper based on all-dielectric Huygens' metasurfaces [1], operating at telecom wavelengths. Our beam-shaper consists of arrays of subwavelength silicon nanodisks that are fabricated using electron-beam lithography and reactive-ion etching on silicon-on-insulator wafers. The nanodisks radiate as a pair of crossed electric and magnetic dipoles, similar to Huygens' sources [2], and are characterized by their spectrally overlapping Mie type electric and magnetic resonances, which produce a 2ϖ phase shift at the resonance. Exploiting the large range of phase shift achievable, we arrange 4 arrays of nanodisks with different lattice periodicities in quadrants such that each quadrant imposes a phase shift of 0, ϖ/2, ϖ or 3ϖ/2 radians onto the incident light. Such arrangement of our nanodisks leads to a transmittance-phase singularity at the center of the incident beam, hence producing a vortex beam. The symmetric and lossless silicon nanodisks allow us to achieve a polarization-insensitive beam conversion with over 70% transmittance efficiency, reassuring the practicality of low loss functional flat optics.

[1] M. Decker et al., Adv. Opt. Mater., DOI: 10.1002/adom.201400584 (2015).

[2] I. Staude, et al., ACS Nano, 7, 7824 (2013).

9668-70, Session 3C

Dipole-fiber systems: radiation field patterns, effective magnetic response, and two-dimensional effective cavities *(Invited Paper)*

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As was shown recently [Opt. Exp. 22, 11301 (2014)], a dipole located at the core-cladding interface of a longitudinally invariant fiber creates an effective two-dimensional cavity for higher-order modes. Strong resonance peaks are observed in the radiation modes, which overlap with the positions of TE polarized whispering-gallery modes formed in a two-dimensional circular cavity with an identical radius as the fiber. Here, we study the radiation peaks and field patterns of dipole-fiber systems and reveal that the field pattern clearly indicates the formation of a two-dimensional cavity for higher-order modes. We show that the strong high-order resonance peaks in the radiation modes overlap with the position of TM guided modes. In addition, we find that the first radiation peak of the ?-oriented dipole-fiber system has contribution only from TE radiation mode, while the first peak of the r-oriented dipole-fiber system has strong contribution of both TE and TM radiation modes. The relative contribution of TE and TM radiation modes in the system depends on the refractive index of the fiber. Furthermore, we find that the field pattern of the first resonance of a ?-oriented dipole in an electric dipole-fiber system can lead to an induced magnetic dipole. We analyze the magnitude of this dipole both numerically and analytically.

9668-71, Session 3C

Persistent flows of exciton-polariton quantum fluid in semiconductor microcavities

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Exciton polaritons, which are quasiparticles arising from strong coupling between photons confined in a microcavity and excitions in a quantum well, are attracting considerable attention due to the rapid growth of interest in non-equilibrium and open-dissipative systems. When exciton polaritons undergo Bose-Einstein condensation into a coherent macroscopically ocupied quantum state, their eventual decay releases coherent photons and results in a fully coherent cavity photoluminescence. Therefore, condensed microcavity polaritons can be used as a new kind of coherent light source. The emitted light inherits the spatial distribution patterns of density and spin from the condensate, which enables in-situ probing of the condensate, as well as engineering of topologically non-trivial light that carries orbital angular momentum (OAM). The latter corresponds to persistent currents of the exciton-polariton quantum fluid. Since polariton systems are intrinsically open-dissipative, the question of influence of pumping and decay processes on the stability properties of persistent currents is highly nontrivial. We address this question by developing a stability theory for persistent currents in polariton quantum fluids supported by all-optical annular confinement. We show, theoretically and numerically, that the system can sustain metastable persistent currents in a large parameter region, and describe scenarios of the supercurrent decay due to the dynamical instability. Furthermore, we discuss methods of generating persisting flows in the condensate either coherently or incoherently. And finally, we extend the results to a two-component condensate with an intrinsic Rashba-like spin-orbit interaction and discuss generation of half-vortices and spin waves in the annular confinement geometry.

9668-72, Session 3C

Reflectionless propagation and interaction of whispering gallery modes in fiber resonators

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We propose an idea of employing reflectionless potentials in the Surface Nanoscale Axial Photonics (SNAP) devices to achieve precise control of propagating signal while eliminating the unwanted reflections. SNAP device is made of an optical fiber with a nanoscale variation of its radius and supports Whispering Gallery Modes (WGMs), which can slowly propagate along the fiber. Such devices have recently attracted a lot of attention due to experimental demonstrations of low loss and sub-nanometer fabrication precision, which can meet most demanding application requirements. The properties of WGMs in such systems are controlled by the variation of the effective fiber radius, which introduces an effective potential for optical waves.

We demonstrate that special variation of the effective fiber radius creates an effective reflectionless potential, enabling gradual propagation of WGMs along the fiber. We show that reflectionless modulations can realize control of transmission amplitude and temporal delay, while enabling close packing due to the absence of cross-talk in contrast to conventional potentials. Importantly, such potentials can be readily realized experimentally in a SNAP fiber platform.

We also derive coupled-mode equations describing nonlinear coupling of multiple WGMs of different orders in a SNAP fiber, taking into account the medium dispersion by using Lorenz reciprocity relations for the Maxwell equations. These equations enable modelling of spatio-temporal dynamics across a broad bandwidth.

Obtained results will stimulate new advances in the design and optimisation of optical micro-resonators, which can enhance various applications including signal control, sensing, comb generation, and spontaneous frequency mixing in the quantum regime.

9668-73, Session 4A

Electrodeposited p-type Co3O4 with high photoelectrochemical performance in aqueous medium

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p-Type Co3O4 photocathodes with different amounts of CuO, were synthesized on fluorine doped tin oxide (FTO) via electrodeposition from a chloride bath containing suspended starch particles. All of the fabricated samples were photoresponsive toward water splitting in 0.5 M Na2SO4 under simulated sun-light. The PEC performance was evaluated using LSPV, chronoamperometry, and EIS techniques. The samples fabricated via the electrodeposition/anodizing/annealing process showed greater photocurrent response compared to the electrodeposition/annealing process. Among all the samples, the sample with an atomic composition% of Co: 24.9, Cu: 25.0 and O: 50.1 showed an optimum photocurrent response (~6.5 mA cm-2 vs. SCE at -0.3 V). The structure, morphology/composition and optical response were characterized by XRD, FESEM/EDX and UV-Vis techniques, respectively.

9668-74, Session 4A

Designing small molecule polyaromatic p- and n-type semiconductor materials for organic electronics

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By combining computational aided design with synthetic chemistry, we are able to identify core 2D polyaromatic small molecule templates with the necessary optoelectronic properties for either p- or n-type materials. By judicious selection of the functional groups, we can tune the solubility of the material making them amenable to solution and vacuum deposition. In addition to solubility, we observe that the functional group can influence the thin film molecular packing. By developing structure-property relationships (SPRs) for these families of compounds we observe that some compounds are better suited for use in organic solar cells, while others, varying only slightly in structure, are favoured in organic field effect transistor devices. We also find that the processing conditions can have a dramatic impact on molecular packing (i.e. 1D vs 2D polymorphism) and charge mobility; this has implications for material and device long term stability. We have developed small molecule p- and n-type materials for organic solar cells with efficiencies exceeding 2%. Subtle variation in the functional groups of these materials produces p- and n-type materials with mobilities higher than 0.3 cm2/Vs. We are also interested in using our SPR approach to develop materials for sensor and bioelectronic applications.

9668-75, Session 4A

Theoretical and experimental investigation of a nanofluid receiver employed in a low profile concentration solar thermal collector

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Recent studies [1-3] have demonstrated that nanotechnology, in the form of nanoparticles suspended in water and organic liquids, can be employed to enhance solar collection via direct volumetric absorbers. In this paper, a low profile (< 15 cm height) solar collector based on direct volumetric absorption is presented. The design aims to develop a commercial solar thermal collector which, through careful optical and thermal control, can supply thermal energy in the 100-250 ? range (currently met by gas and electricity).

A full-scale prototype has been developed consisting of three volumetric absorbers. As reported previously [4], a novel linear optical tracking system was developed to simplify the tracking mechanism so that it integrates well with rooftops. The present study will focus on the performance of the ITO-coated quartz glass pipe used to contain chemically functionalized multi-walled carbon nanotubes (MWCNTs) dispersed in DI water or Therminol 55. MWCNTs (average diameter of 6-13 nm and average length of 2.5-20 ?m) were functionalised by potassium persulfate as an oxidant. The nanofluids were prepared with a MCWNT concentration of 50± 0.1 mg/L to form a balance between solar absorption depth and pumping power. These nanofluids have very high solar absorption, while the 100 nm thick the ITO coating is used to reduce the radiative emission from the glass pipe, vacuum insulation is also employed around the volumetric absorber to minimize conductive and convective heat loss from the volumetric absorber.

Optical and thermal experimentation reveal that the collector efficiency ranges from 20% - 40% to maintain an output temperature of 200 ? between 9 am and 3 pm on a sunny day. Overall, the proposed collector design represents a low-cost and effective way to bring nanotechnology into industrial and commercial heating applications.

9668-76, Session 4A

The design of the Fano resonances in oligomer-like structures

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It is not widely acknowledged that the optical response associated with a Fano resonance varies depending on the interfering eigenmodes that produce it. Here we show that generalizing Fano resonances as instances of nonorthogonal eigenmodes [1] provides a way to understand and categorize both the resulting near and far field effects of a Fano resonance. In this sense, we can investigate the general optical behavior arising from destructive and constructive interplay between independently driven resonances. For instance, the magnitude of a Fano resonance's signature in transmission can be related to that in the total scattered field and thereby a similarity of the farfield scattering profile of the involved eigenmodes. Conversely, a Fano resonance made from the overlap between eigenmodes that preferentially scatter and absorb light does not necessarily produce such strong features in transmission, but it does afford a way to interchange the combined optical response between absorption and scattering. Here we investigate different forms of modal overlap afforded by multistep coupling channels formed between subsystems and also by the direct channels produced by bianisotropic coupling between high-index dielectric nanoparticles. Examples of this behavior can be found in small assemblies of nanoparticles, which we can utilize to demonstrate the range of optical responses present in Fano resonances [2]. We thereby illustrate a more directed use of Fano resonances to produce novel optical behavior in nanoantenna and metasurface scattering geometries.

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9668-77, Session 4A

Optical properties of arrays of five-pointed nano-stars

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The optical properties of nanostructures are the critical parameters for nano-optical applications based on localized surface plasmon resonances. In this paper, we explore the effect of material-of-construction on the transmittance and near-field optical intensity of arrays of closely-spaced five-pointed nano-stars. We use the finite-difference time-domain (FDTD) numerical simulation method and the materials investigated were silver (Ag), gold (Au), copper (Cu) and aluminum (Al). The nano-stars were 500 nm across and 40 nm thick and separated from another by a gap of 80 nm. The study showed that the material used had a significant effect on the optical properties of these arrays. The localized optical intensity of Al is less than that of other three materials within the range of simulation wavelengths. This indicates that Al nano-stars of this shape would not be suitable for plasmonic applications in the visible or near-infrared.

9668-78, Session 4A

Plasmonic response in nanoporous metal: dependence on network topology

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The unusual optical and electrical responses of open metal networks have suggested their application in a variety of technologies including transparent conducting electrodes, charge storage, catalysts and optical switching. The properties of a nano- or mesoporous metal network depends on the shape and volume fraction of individual voids and the associated hyper-dimensional connectivity and density of the metal filaments. The transition from weak connectivity and localized optical response to macroscopic percolation and delocalized response involves a sequence of topologies. In any one sample there is often a broad admix of local void topologies. In the percolation zone signature topological features emerge, making the transition through percolation both complex and interesting. These phenomena have been studied in a range of Au and Ag sponges produced by etching of alloys. Generally de-alloying of precursor generates a fibrous sponge but other complex networks will also be discussed.

Dynamic re-assembly of the remaining material during the de-alloying is time-and temperature-dependent. The modeling process yields classic fibrous sponges as observed experimentally. The optical properties of cubic blocks of the sponges were modeled. The aim of the present work is to link associated topological characteristics given by the distribution of Mean or Gaussian curvature in orthogonal directions, to the final plasmonic optical response. These orthogonal topologies can also help explain significant and useful anisotropies in the plasmonic and electrical response including the effective plasma frequency.

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9668-79, Session 4A

Optimization of effective absorption enhancement of paired-strips gold nanoantennas arrays in organic thin-films

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In plasmonic nanoantennas, near-field enhancement is strongly related to the spacing between paired nanoparticles, which enables the confinement of oscillating electrons within the gap. Relative to other types of nanoantenna, such as bowtie, nano-disk, and mesh, paired-strips nanoantennas provide greater enhancement spacing. To understand electromagnetic behavior of nanostructure arrays, previous researchers have investigated the spectral properties, resonance, and near- and far-field energy intensities. Considerable attention has been paid to analysis of the electric field via integration. However, little research has been conducted into optimizing the dimension of nanostructures with gaps embedded within a given volume. It is considering not only a tradeoff between the size of the nanostructures and the volume of the absorber layer, but also the appropriate gaps, to maximize the effective absorption. At first, two of the dimensional parameters are fixed to find the best range of values of the other dimension. Then, based on the 2D maps, the average absorption 3D slices plot were derived, in which the dimension width, height, and gap are changed with a fixed wavelength, and the optimized dimension of paired-strips nanoantennas could be realized. In conclusion, when two resonance bands across, there is not only the highest average electric field enhancement, but also the largest mode area, which can be regarded as the concentrated electric field is distributed in the absorbent layer uniformly, resulting in a maximum absorption. For gold paired-strips nanoantennas embedded in a 120 nm P3HT:PCBM thin-film, the absorption enhancement could reach 9.85 times.

9668-80, Session 4A

Graphene nano-ribbon with nano-breaks as efficient thermoelectric device

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Thermoelectricity, one of the sources of alternative energy, has been restricted to niche applications due to its low efficiency. In this work, we utilize some of the unique properties of graphene in order to achieve a highly efficient thermoelectric device. It has been well established that delta-like transport distribution of electrons gives rise to highly enhanced thermoelectric performance. It has also been experimentally verified that graphene nano-ribbons with nano-breaks in their channel region exhibit tunnelling. Here, we utilize the tunnelling phenomena observed in graphene break junctions in order to realize thermoelectric devices with delta-like transport distribution, and study their properties using quantum mechanical simulations.

Our proposed devices promise ZT values ranging from 10 to 100. These high ZT values can be attributed to complete blockage of phonon transport due to the presence of the breaks. The electrical conductance is also suppressed, except near the tunnelling energy where it becomes highly pronounced, giving rise to an enhanced ZT value. In this report we investigate the effect of varying the width and the edge orientation of the nanoribbon, as well as the dimension of the break region, on the device's overall thermoelectric properties. Moreover, we investigate the effect of temperature and edge roughness on tunnelling and how it affects thermoelectric performance. In the presented simulations, we employed a Density Functional Theory (DFT) in order to obtain the electrical properties, assuming ballistic transport. The phononic system was characterized using a Tersoff empirical potential model. The proposed devices have potential applications as two-dimensional nanoscale local coolers and as thermoelectric power generators when connected in arrays.

9668-81, Session 4A

Modeling of graphene nanoscroll conductance with quantum capacitance effect

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Graphene nanoscrolls (GNSs) as a new category of quasi one dimensional materials belong to the carbon-based nanomaterials which have recently captivated the attention of researchers. The latest discoveries of the exceptional structural and electronic properties of GNSs, like high mobility, controllable band gap and tunable core size has become a new stimulus for researchers. Fundamental descriptions about the structure and electronic properties of GNSs as a new semiconducting material have been investigated in order to apply them in nanoelectronic applications such as in nanotransistors and nanosensors. By utilizing a novel approach and including the effect of quantum capacitance, the analytical conductance model (G) of GNSs is derived. The approach is to introduce a geometry-dependent model in order to obtain the conductance of GNSs. Using this model, the conductance performance of the GNS is analyzed. The conductance of GNS in the parabolic part of the band structure, also the temperature-dependent conductance, which displays minimum conductance near the charge neutrality point, are calculated. Subsequently, the effect of temperature and physical parameters on its conductivity is analyzed extensively. The proposed model has been compared with the similar published models on GNSs and carbon nanotubes (CNTs) which showed a satisfactory agreement. In addition, by taking into account the quantum capacitance effect, it was found that the conductance value increases. This study demonstrates that the GNS is a promising candidate for new generation of nanoelectronic devices.

9668-82, Session 4B

Label-free hyperspectral unmixing for differentiate the different treatments with 'stem cell over cartilage' system for regenerative medicine applications

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Adipose-derived stem cells are being used in regenerative medicine for treating a range of diseases in both animals and humans. The treatment of bone and joint disorders such as osteoarthritis with these cells is at the forefront of these new treatments. The cells have been shown to have anti-inflammatory effects within osteoarthritic joints and in some circumstances to aid regeneration of cartilage. These therapeutic effects are known to be driven by secretions from the stem cells. The stem cells embed within the joint and secrete a range of cytokines that drive the therapeutic effect [1-6].

Our recently developed hyperspectral imaging (HSI) technique is able to differentiate stem cells from collagen structure without using any extraneous fluorescent labelling. We have been using this technique to study the interaction of stem cells with cartilage from both human and bovine samples. The method is compatible with established methods of fluorescent biomarker labelling and the hyperspectral unmixing by Dependent Component Analysis (DECA) provides information on the metabolic activity of cells. This allows us to explore the metabolic interactions for different cytokine related treatment at different layer of cartilage and potentially allow us to identify the better treatment for repairing cartilage.

Observing cartilage sample presents a challenge for hyperspectral imaging, because cartilage is strongly autofluorescent. This strong autofluorescence background from different types of collagen tends to overwhelm the fluorescence from other coenzymes and cofactors. We have been successful in using DECA in this cartilage chip model to analyse biochemical profiling without using any extraneous cell labelling.

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9668-83, Session 4B

Nanoparticle-based strategy for ultrasensitive cytokine detection

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Cytokines, immunomodulating protein biomarkers secreted from immune cells, are indicators of the functional status of the human immune system. They play critical roles in regulating cell signalling, cell differentiation, and inflammatory response in the immune system. However, such cytokine related immune reactions are often extremely dynamic and occur quickly. In addition, the produced cytokine concentration is in pM range. Thus, a sensitive and rapid immunoassay that affords comprehensive characterization and quantitative analysis of cytokines secreted from immune cells is the key to precisely determining the subtle variations and the dynamic characteristics of cellular immune functions in the hose. Herein we developed a new nanotechnology strategy with the construction of an immobilised affinity surface being able to specifically capture ultrasamll amount of cytokines. The captured molecules are then detected using fluorescent labelled magnetic beads. The detection mechanism is based on a Sandwich assay, and the detection antibodies were tailored to the fluorescent labelled magnetic beads which are vital to the sensing performance. We have compared the performance of three types of fluoresce nanoparticles (FITC labelled magnetic beads, dragon green labelled magnetic beads, and graphene quantum dots) with respect to the detection of cytokine IL-6. The results shows that the dragon green labelled magnetic beads provided higher sensitivity comparing with other two types of particles. It can pick up the IL-6 from living cells without any stimulation. The immunosensing surface shows high selectivity to IL-6 and is stable for over 30 days. This research holds promise for efficient separation of circulating cancer cells in fresh whole blood.

9668-84, Session 4B

Systematic assessment of biodistribution and blood circulation time of functionalized upconversion nanoparticles in chick embryo

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Nanoparticle-based delivery of drugs and contrast agents holds great promise in cancer research, because of the increased delivery efficiency compared to 'free' drugs and dyes. A versatile platform to investigate nanotechnology is the chick embryo chorioallantoic membrane tumour model, due to its availability (easy, cheap) and accessibility (interventions, imaging). In our group, we developed this model using several tumour cell lines (e.g. breast cancer, colon cancer). In addition, we have synthesized in-house silica coated photoluminescent upconversion nanoparticles with several functional groups (COOH, NH3, PEG). In this work we will present the systematic assessment of their in vitro stability in biological media (PBS, DMEM), in vivo blood circulation times, and in vivo biodistribution in the different organs of the chick embryo.

To this end, we injected chick embryos grown ex ovo (Embryo Development Day 15) with the functionalized UCNPs (50 ?L of 0.5 mg/ml UCNP solution) and obtained a small amount of blood (5 ?L) at several time points after injection ([t = 2 minutes – 24 hours], n = 3 chicks per UCNP-group per time point). In addition, the chicks were sacrificed at different time points and the organs were harvested [t = 20 minutes – 24 hours]. The UCNP signal from the blood smears was quantified using a modified inverted microscope set-up. The integrated UCNP signal from the organs was obtained using whole organ imaging and tissue slices. The results of this systematic study are valuable to optimize biochemistry protocols and guide nanomedicine advancement in the versatile chick embryo tumour model.

9668-85, Session 4B

A wirelessly powered micro-spectrometer for neural probe-pin devices

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Treatment of neurological anomalies, whether done invasively or not, places stringent demands on device functionality and size. We have developed a micro-spectrometer for use as an implantable neural probe to monitor neuro-chemistry in synapses. The micro-spectrometer, based on a NASA-invented miniature Fresnel grating, is capable of differentiating the emission spectra from various brain tissues. The micro-spectrometer meets the size requirements, and is able to probe the neuro-chemistry and suppression voltage typically associated with a neural anomaly. This neural probe-pin device (PPD) is equipped with wireless power technology (WPT) to enable operation in a continuous manner without requiring an implanted battery. The implanted neural PPD, together with a neural electronics interface and WPT, enable real-time measurement and control/feedback for remediation of neural anomalies. The design and performance of the combined PPD/WPT device for monitoring dopamine in a rat brain will be presented to demonstrate the current level of development. Future work on this device will involve the addition of an embedded expert system capable of performing semi-autonomous management of neural functions through a routine of sensing, processing, and control.

9668-86, Session 4B

Multimode fibres: a pathway towards deep-tissue fluorescence microscopy

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Multimode optical fibres are emerging as a powerful micro-endoscopy platform in life sciences thanks to their (i) extremely small footprint (as small as tens of micrometers) and (ii) their ability to support advanced fluorescence imaging methods. However, their applications in deep-tissue imaging are hindered by the lack of flexibility and by high demands on computational power. Here, we present a portfolio of our recent studies that address these issues and thus pave the way for novel, minimally invasive deep-tissue imaging applications.

9668-87, Session 4B

In-vivo and In-vitro fluorescence quenching of NADH by FCCP

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Carbonyl cyanide-p-trifluoro methoxyphenylhydrazone (FCCP) is a well-established uncoupling agent for mitochondria. Nicotinamide Adenine Dinucleotide (NADH) is a key native fluorophore in cells and tissues of key relevance to cell metabolism and its fluorescence is quenched by FCCP. Chemical abundance maps of native fluorophores in unlabelled cells and tissues can be non-invasively obtained by multispectral fluorescence microscopy followed by spectral unmixing. The unmixing procedure bears some similarity to curve fitting, and it needs to be validated in live cells and tissues, by demonstrating that the unmixed molecular components are suppressed by chemical fluorescence quenching. This is challenging because cells respond to chemical fluorescence quenchers in unexpected ways. Here we investigate fluorescence quenching of a key cellular fluorophore NADH with FCCP both in-vitro and in cultured HeLa cells. We quantify free and bound NADH content in cell before and after exposure to FCCP for a broader range of FCCP concentrations (50-1000μM) than previously used. We confirm that FCCP quenches free NADH fluorescence. We observed some recovery of NADH fluorescence in plated cells around 300 μM of FCCP. At the same time the flavin concentration has not been affected by FCCP. Confocal microscopy of JC1-labelled cells confirms that NADH concentration in FCCP exposed cells decreased. We have also proved using NADH detection kit that FCCP selectively affects average NADH concentration. This work confirms that we are able to non-invasively identify NADH in cells and tissues by multispectral fluorescence microscopy followed by unmixing. Our method provides maps of chemical abundance of this and other fluorophores, of significance in cell biology.

9668-88, Session 4B

Optical parameter measurement of highly diffusive tissue body phantoms with specially designed sample holder for photo diagnostic and PDT applications

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Knowledge of optical properties (absorption coefficients, scattering coefficients, and refractive index) is necessary for understanding light tissue interactions. Optical parameters define the behavior of light in the tissues. Intralipid and Indian ink are well-established tissue body phantoms. Quantitative characterization of biological tissues in terms of optical properties is achieved with integrating sphere. However, samples having significantly higher scattering and absorption coefficients such as malignant tissues potentially reduce the signal to noise ratio (SNR) and accuracy of integrating sphere. We have measured the diffuse reflection and transmission of these phantoms by placing them in integrating sphere at 632.8 nm and then applied IAD method to determine the optical properties tissue phantoms composed of Indian ink (1.0%) and Intralipid (20%). We have fabricated a special sample holder with thin microscopic cover slips which can be used to measure signal from highly concentrated intralipid and Indian ink solutions. Experiments conducted with various phantoms reveal significant improvement of SNR for a wide range of optical properties. This approach opens up a field for potential applications in measurement of optical properties of highly diffusive biological tissues. For 20% intralipid μa =0.112±0.046 cm-1 and μs =392.299±10.090 cm-1 at 632.8 nm and for 1.0% Indian ink μa =9.808±0.490 cm-1 and μs =1.258±0.063 cm-1 at same wavelength. System shows good repeatability and reproducibility within 4.9% error. Results show that small variations in Intralipid and/or Indian ink concentration leads to significant change in output optical properties which may have important bio-medical applications in photo-diagnosis and Photo-dynamic therapy.

9668-90, Session 4C

Improved properties of phosphor-filled luminescent down-shifting layers: reduced scattering, optical model, and optimization for PV application

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We study the optical properties of polymer layers filled with phosphor particles in two aspects. First, we used two different polymer binders with refractive indices n=1.46 and n=1.61 (?=600 nm) to decrease ?n with the phosphor particles (n=1.81). Second, we prepared two particle size distributions D50=12 µm and D50=19 µm. The particles were dispersed in both polymer binders in several volume concentrations and coated onto glass with thicknesses of 150-600 µm. We present further a newly developed optical model for simulation and optimization of such luminescent down-shifting (LDS) layers. The model is developed within the ray tracing framework of the existing optical simulator CROWM (Combined Ray Optics / Wave Optics Model), which enables simulation of standalone LDS layers as well as complete solar cells (including thick and thin layers) enhanced by the LDS layers for an improved solar spectrum harvesting. Experimental results and numerical simulations show that the layers of the higher refractive index binder with larger particles result in the highest optical transmittance in the visible light spectrum. Finally we proved that scattering of the phosphor particles in the LDS layers may increase the overall light harvesting in the solar cell. We used numerical simulations to determine optimal layer composition for application in realistic thin-film photovoltaic devices. Surprisingly LDS layers with lower measured optical transmittance are more efficient when applied onto the solar cells due to graded refractive index and efficient light scattering. Therefore, our phosphor-filled LDS layers could possibly complement other light-coupling techniques in photovoltaics.

9668-91, Session 4C

Improved-performance polymer solar cells employing nano-patterned electrodes

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Polymer solar cells (PSCs) have been regarded as the future alternative of conventional silicon solar cells due to many advantages, such as eco-friendly, low-cost, transparency, and flexibility [1]. However, conventional PSCs have limitations due to intrinsic optical and electrical properties. Optically, the mismatch between the solar spectrum and the absorption spectrum of organic layer restricts exciton formation, thus resulting in a low short circuit current. Electrically, unbalanced charge collection by the anode and cathode of a PSC leads to an s-shaped I-V curve, which significantly decreases the fill factor of the PSC.

Several attempts have been tried to improve the optical or electrical performance, but not simultaneously[2, 3]. In this work, we show that by nano patterning the metallic electrode of PSCs, the light absorption and the balanced electron-hole collection of PSCs can be simultaneously enhanced. Experimental results show that for a PSC employing a gold electrode that is nano-patterned with a triangular-shaped rods of size around 250 nm and period around 580nm, acting as the hole injection layer, the short circuit current and fill factor can be increased by 6% and 30%, respectively, thus leading to an increase in power conversion efficiency by 40% for a single-junction PSC.

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9668-92, Session 4C

Fiber energy devices: from micro/nano-structured electrodes to wearable-energy applications

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Benefiting from the rapid progress of nanomaterials and micro processing technologies, flexible electronics have attracted worldwide attention for developing wearable electronic devices and smart systems. As an emerging type of flexible electronics, fiber electronics are quite promising for advancing flexible and weavable multifunctional E-textiles. To provide energy for various functional electronic device units, suitable fiber energy harvesting/storage devices are required. To this end, fiber solar cells for potable and cost-efficient flexible energy harvesting are developed. Being made from well designed micro/nano structured electrodes, the state-of-the-art fiber solar cells can achieve power conversion efficiencies of above 8%. Compared with common planar solar cells, fiber solar cells are totally TCO-free, flexible and possess outstanding 3-D light harvesting capacity, which are feasible for utilizing low-cost materials (e.g. metal wires and carbon fibers) and diverse optical designs. Thus, flexible fiber solar cells with considerably high cost-performance were achieved. For example, the power output of a fiber solar cell can be enhanced by a factor of two to five with a simple micro-concentrator. Based on the similar design concept of fiber solar cells, novel flexible fiber energy storage devices (e.g. supercapacitors and batteries) prepared from functional micro-wires and active materials are reported, which advantage in high flexibility, considerable durability, easy scale-up and low cost for efficient electrochemical energy storage. Moreover, the electrochemical performances of fiber energy storage devices can be comparable to those of typical planar energy storage devices after rational design of device architecture and active materials. Due to the unique fiber architecture, both fiber solar cells and fiber energy storage devices can be easily connected to achieve device modules for efficient energy harvesting and storage, either individually or jointly for integrated energy utilization. To realize lower cost, lighter and more efficient flexible/wearable energy conversion and storage devices/systems toward practical applications, further development of efficient materials, interface engineering and collaborative optimizations of device components are possible research avenues and may also bring new fascinations for portable flexible electronics.

9668-93, Session 4C

Nanostructured metallic rear reflectors for thin solar cells: balancing parasitic absorption in metal and large-angle scattering

Claire E. R. Disney, Supriya Pillai, Martin A. Green, The Univ. of New South Wales (Australia)

Rear reflectors for solar cells comprised of metal films with periodic arrays of nanoscale features on their surface can provide significantly enhanced light trapping in the absorber layer. However, these structures can also result in significantly increased parasitic absorption into the metal layer at various wavelengths of light. Conversely, these highly absorbing resonances can also coincide with the wavelengths which display the largest enhancement to the cell's photocurrent. As such it is important to understand the underlying causes for such photocurrent enhancements and losses in the metal in order to design optimum structures for use.

3D Finite-difference-time-domain simulations have been used to model a variety of structures and analyse the spatial distribution of absorption within different materials which make up the structure, the angles at which light will be scattered from the rear surface, as well as the

idealized short circuit current from each structure normalized to the AM1.5 spectrum. These reveal the properties of these modes at resonant wavelengths at which absorption into both materials is enhanced. Despite the enhanced coupling of light into the metal at these wavelengths, the amount of light scattered back into the absorber at large angles is also significantly boosted. For a large variety of geometries, the impact of this large angle scattering dominates leading to significant increases to a cell's photocurrent. Our simulations allow us to understand the contributions of multiple plasmonic effects occurring in such structures, allowing selection of the most suitable geometries to achieve large-angle scattering in a desired wavelength range.

9668-94, Session 4C

Novel plasmonics materials to improve thin film solar cells efficiency

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Thin film solar cells have been vastly studied in the last years due to the promise of reduced cost in photo-voltaic systems commercialization. However, they possess low photon conversion efficiency and intrinsic low light absorption characteristic, hampering their further advances. Progress on improving light trapping and absorption within the thin active layer have been in part achieved by texturing or nano-structuring the surface thus increasing the light path length, as well as developing antireflection coating. Another approach is using plasmonic effects in metal nanoparticles. However, metal plasmonics nanoparticles also stop the light to enter in the active layer, induce further recombination effects and thermal effects due to their intrinsic losses in the near infrared. Thus experimental implementations of thin-film metal based plasmonics solar cell did not provide the expected enhancement of the overall cell photon conversion efficiency. Recently, highly metal doped semiconductor oxides have been proposed as alternative low losses materials for application of plasmonics effects in nanophotonics and opto-electronics.

In this work we numerically investigate the effect of recently discovered novel plasmonic in highly doped-oxide semiconductor, such as Aluminum doped ZnO, and its possible new role as plasmonic material in photovoltaics applications. We examined both sub-micron film of this material that can be also used directly as contact layer thus avoiding metal back contact plasmonics absorption in the near infrared and its nanoparticles counterpart used in place of metal plasmonic nanoparticles.

9668-95, Session 4C

Ultrafast charge generation and relaxation dynamics in methylammonium lead bromide perovskites

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The rapid development of organic-inorganic halide perovskite solar cell has generated intense research interests. Although $CH_3NH_3PbI_3$ is the most invesitaged material so far, $CH_3NH_3PbBr_3$ has a larger bandgap (~2.3 eV) allowing larger voltage potential, suitable for a tandem device [1]. Demonstration of the bromide based perovskite solar cell thus far has involved the use of various hole transport materials (HTM) and fabrication techniques [1-3]. It is also important to understand the carrier dynamics such as electron-hole pair separation, relaxation and recombination, so to aid the optimization of solar devices that are efficient in extracting the photogenerated carriers before they recombine. In this work, we study the carrier dynamics in bromide based perovskites using ultrafast transient absorption spectroscopy with a time scale of femtosecond and picosecond. The transient absorption spectra show two bleaching signals. One of which is a strong and narrow signal centered at 536nm due to the occupation of conduction band by excited electrons. The other one is a weak and broad signal in the vicinity of 630nm due to excitonic traps [4]. 'Blue band absorption' is also observed at the shorter wavelengths (~500-520 nm) whereby absorption becomes slightly larger after excitation. Similar change can be found for wavelengths between ~680 and 740 nm, possibly be due to excited-state absorption [5]. The kinetic traces near the band-edge reveal a ~2ps process of hot carrier cooling [6]. Upon increasing excitation intensity, the photoexcited carriers exhibit higher relaxation rate, suggesting high order mechanisms.

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9668-96, Session 4C

Performance, morphology, and photophysics of high open-circuit voltage, low band gap all-polymer solar cells

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Using a polymer acceptor instead of fullerene can have certain advantages in terms of higher absorption coefficients, chemical tunability to alter LUMO levels for better charge separation and superior flexibility in controlling solution viscosity for large area and high through-put processing.

Recently so-called all-polymer solar cells have reported efficiencies ~ 6 % but are still lagging behind their fullerene counterparts. In this work we use various tools to build an overarching understanding of the morphology, microstructure and photo-physics of all-polymer cells with a view to diagnosing the reasons limiting higher efficiencies. The donor material BSF4 is a low band-gap co-polymer based on dithienyl-benzo[1,2-b:4,5-b]dithiophene (DT-BDT) and 5-fluoro-2,1,3-benzothiadiazole (FBT) sub-units with the naphthalene diimide/thiophene co-polymer P(NDI2OD-T2) used as the acceptor.

Transmission electron microscopy reveals a relatively coarse phase-separated morphology, with elongated domains up to 200 nm in width. Near-edge X-ray absorption fine-structure (NEXAFS) spectroscopy and atomic force microscopy (AFM) measurements reveal that the top surface of BFS4:P(NDI2OD-T2) blends is covered with a pure BFS4 capping layer. Depth profiling measurements confirm this vertical phase separation with a surface-directed spinodal decomposition wave observed. Grazing-incidence wide-angle X-ray scattering (GIWAXS) measurements confirm that BFS4 and P(NDI2OD-T2) are semicrystalline with both polymers retaining their semicrystalline nature when blended. Photoluminescence spectroscopy reveals incomplete photoluminescence quenching with as much as 30% of excitons failing to reach a donor/acceptor interface, confirmed further by Transient absorption spectroscopy measurements. Thus while the BSF4/P(NDI2OD-T2) system shows a promising efficiency, many of the limiting characteristics of all-polymer blends such as large domains and fast geminate recombination appear to remain

9668-97, Session 4C

Nanosphere lithography for improved absorption in thin crystalline silicon solar cells

Yuan-Chih Chang, David N. Payne, Michael E. Pollard, Darren M. Bagnall, The Univ. of New South Wales (Australia)

Plasmonic nanoparticle arrays have been studied for their light trapping potential in thin film solar cells. However, the commercial use of such arrays has been limited by complex and expensive fabrication techniques such as photolithography and electron beam lithography. Moreover, previous studies typically investigated numerical optimization of the array parameters in isolation or as part of a back contact only. In this paper, we aim to explore the entire parameter space in a complete thin film solar cell device structure environment economically. Accurate and meaningful results for the optical enhancement caused by nanoparticle arrays have been determined using modelling via finite difference time domain (FDTD) simulations. Parameters such as TCO thickness, nanoparticle capping layer and array period have been explored and optimized with the simulation results first verified by agreement with optical measurements of electron beam fabricated test structures. The complete device simulation allows for a clear understanding of the origins of any absorption enhancement as well as efficient optimization. Furthermore, the use of nanosphere lithography (NSL) as a solution-based method for forming regular nanoscale array films is investigated. Deposition of the polystyrene monolayer has been optimised to provide a uniform nanosphere mask thus ensuring the quality of the nanostructured metal film. The optimised method allows for a closer match between the simulated ideal structure and economically fabricated arrays. Finally, the optimized plasmonic nanoparticle arrays have been incorporated into preliminary, proof of concept devices in order to determine and demonstrate their potential for improving the optical response of a solar cell using economical and scalable methods.

9668-98, Session 4C

To improve moisture stability of perovskite solar cells by hydrophobic hole transporting system without lithium salt additive

Lixin Xiao, Peking Univ. (China)

Non-ion additive hole-transporting material (HTM) of hydrophobic oligothiophene derivative named DR3TBDTT and triphenylamine derivative of N,N?-di(3-methylphenyl)-N,N-diphenyl-4,4-diaminobiphenyl (TPD) were used for the organic-inorganic hybrid perovskite solar cells. The power conversion efficiency (PCE) was comparable to the device using Li-TFSI doped spiro-MeOTAD. Moreover, the PCE decreases by only 10% after approximately 1000 h without encapsulation, which suggests an alternative method to improve the stability of perovskite solar cells.

9668-502, Session Plen

Photonics beyond diffraction limit: plasmon waveguide, cavities, and integrated laser circuits

Xiang Zhang, Univ. of California, Berkeley (United States)

No Abstract Available

9668-99, Session 5A

Nanoengineered plasma polymer films for biomedical applications *(Invited Paper)*

Krasimir Vasilev, Univ. of South Australia (Australia)

In my talk I will present recent developments from our group on various nanoengineered biomaterial coatings that are facilitated by plasma deposition. These include antibacterial coatings, drug release platforms and cell guidance/capture surfaces.

We have developed various strategies for generation of antibacterial coatings that can be applied to medical service surfaces. These involve means such as surface silver nanoparticles, antibiotics, nitric oxide, quaternary ammonium compounds (QACs) or simply coatings that have intrinsic low fouling properties. Important for applications, we not only extensively test our coating for their antibacterial efficacy but also assess their potential cytotoxicity to mammalian cell and inflammatory consequences. We have also developed methods for the synthesis and surface immobilisation of hybrid antibacterial nanocapsules and nanoparticles.

My talk will also outline our research on advanced plasma polymer based coatings capable of directing cellular behaviour. We have developed a range of surface gradients such as of chemistry, bound ligand and protein densities, nanomechanics and nanotopography. We have used these gradients to interrogate the behaviour of various cell types, including stem cells. In my talk, I will focus on recent work where we used gradients of nanoparticles density to study the influence of surface nanotopography of cell behaviour. Our data demonstrates that surface nanotopography strongly affects the adhesion of fibroblasts and osteoblasts, and alters the level of expression of pro-inflammatory cytokines from microphages and neutrophils. I will present a strategy for developing gradients of surface elastic modulus. Our studies on the adhesion and proliferation of primary human fibroblasts show that these cells prefer stiffer surfaces. I will also present our surfaces that are capable of driving the differentiation of stem cells via surface chemistry, nanotopography or density of signalling molecules.

9668-100, Session 5A

First principle study on biocompatible lead-free piezoelectric materials

Tomoya Kai, Yasutomo Uetsuji, Osaka Institute of Technology (Japan); Kazuyoshi Tsuchiya, Tokai Univ. (Japan)

Biocompatible piezoelectric materials are becoming increasingly important for actuators and sensors in medical devices, such as health monitoring systems and drag delivery systems. In this study, we challenged to derive novel piezoelectric materials with biocompatibility and to present their phase diagrams by first principles calculations. Firstly, biocompatible constituent elements have been specified by HSAB (Hard and Soft Acids and Bases) method from the viewpoint of interaction energy with in-vivo molecules. Secondly, in order to create a perovskite-type crystal structure ABO3, which has excellent piezoelectric response, the combination of biocompatible elements was selected to satisfy geometric stable condition defined by tolerance factor. And then the stable cubic structure at paraelectric non-polar phase and the stable tetragonal structure at ferroelectric phase were analyzed for the discovered oxides by first principles DFT. The total energy, spontaneous polarization and piezoelectric stress constants were estimated and compared among the discovered oxides.

On the other hand, their phase diagrams were calculated to fabricate the novel piezoelectric thin films for MEMS (Micro Electro Mechanical Systems). Concretely, total energy and spontaneous polarization were approximated by Gibbs function based on a thermodynamic theory. The stable phase with minimum energy was found by the approximated energy function. The developed approach was verified by some existing oxides such as BaTiO3 and PZT, and then it was applied to the discovered oxides. Especially, the effect of misfit strain on phase diagram was discussed for the novel piezoelectric thin films on substrate.

9668-101, Session 5A

Multiscale simulation of polycrystalline ferroelectric materials

Tatsuya Oka, Yasutomo Uetsuji, Hiroyuki Kuramae, Osaka Institute of Technology (Japan); Kazuyoshi Tsuchiya, Tokai Univ. (Japan)

A multiscale finite element modelling based on crystallographic homogenization theory is presented for polycrystalline ferroelectric materials with morphotropic phase boundary (MPB). The purpose of this study is to reveal nonlinear behaviors caused by domain switching and to design micro- and nano-structures of biocompatible piezoelectric materials.

PZT is used widely for actuators and sensors of electromechanical devices and it has multiple crystal systems. Although PZT outputs large piezoelectricity, it shows a complicated hysteresis behavior caused by domain switching and structural phase transition at MPB. It is important for development and improvement of biocompatible lead-free piezoelectric materials to understand the mechanism of huge piezoelectricity in PZT. In this study, a multiscale nonlinear finite element method was developed to estimate ferroelectric material properties. The homogenization theory was employed for scale-bridging between macrostructure and microstructure. We utilized an incremental form of fundamental constitutive law in consideration with physical property change caused by domain switching and structural phase transition. Crystal morphologies, which are characterized as an inhomogeneous structure composed of many grains and domains with individual orientations, are modeled at a micro scale. Then the homogenized material properties of macrostructure can be estimated with perfect correlation to microstructural changes such as domain switching and structural phase transition. The proposed multiscale finite element method was applied to a polycrystalline PZT, and the relation between the macroscopic properties and microscopic domain switching and structural phase transition were investigated. Especially the difference among tetragonal single phase, rhombohedral single phase and their dual phases were discussed.

9668-102, Session 5A

Acellular organ scaffolds for tumor tissue engineering

Anna Guller, Macquarie Univ. (Australia) and I.M. Sechenov Moscow Medical Academy (Russian Federation); Inna Trusova, Elena Petersen, Moscow Institute of Physics and Technology (Russian Federation); Anatoly B. Shekhter, I.M. Sechenov Moscow Medical Academy (Russian Federation); Yi Qian, Andrei V. Zvyagin, Macquarie Univ. (Australia)

Rationale: Tissue engineering (TE) is an emerging alternative approach to create models of human malignant tumors for experimental oncology, personalized medicine and drug discovery studies. Being the bottom-up strategy, TE provides an opportunity to control and explore the role of every component of the model system, including cellular populations, supportive scaffolds and signalling molecules.

Objectives: As an initial step to create a new ex vivo TE model of cancer, we optimized protocols to obtain organ-specific acellular matrices and evaluated their potential as TE scaffolds for culture of normal and tumor cells.

Methods and results: Effective decellularization of animals' kidneys, ureter, lungs, heart, and liver has been achieved by detergent-based processing. The obtained scaffolds demonstrated biocompatibility and growth-supporting potential in combination with normal (Vero, MDCK) and tumor cell lines (C26, B16). Acellular scaffolds and TE constructs have been characterized and compared with morphological methods.

Conclusions: The proposed methodology allows creation of sustainable 3D tumor TE constructs to explore the role of organ-specific cell-matrix interaction in tumorigenesis.

9668-103, Session 5A

Exploring the nanoscale dynamics of molecular systems with optical microcavities *(Invited Paper)*

Frank Vollmer, Max-Planck-Institut für die Physik des Lichts (Germany)

Medicine as well as biology increasingly rely on the use of cutting-edge physics and engineering, in order to pursue the next generation nanomedical applications and to address fundamental questions in the life sciences. Central to this task is the study of micro- and nano systems, focusing on how engineered systems combined with natural ones can advance sensing, medicine, and our understanding of how biological systems work. My research addresses these important questions with state-of-the-art biosensor technologies, capable of detecting single molecules and their dynamics; and resolving the kinetics of complex molecular systems on timescales ranging from few nanoseconds to several hours.

9668-152, Session 5A

Complementary all-graphene planar self-switching devices

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Self-switching diodes (SSDs) are two-dimensional nanorectifiers that have a range of important applications including microwave and Terahertz detection. Conventional SSDs based on compound semiconductor heterostructures have shown very promising performance as microwave detectors as well as room temperature Terahertz detectors. Recently SSDs based on graphene have been theoretically studied and investigated, showing very promising device capabilities such as rectification, negative differential resistance operation and tunable biosensing. Furthermore, graphene SSDs (G-SSDs) have been experimentally realized, showing promising potential as zero bias microwave detectors. In previous studies we had shown how the performance of G- SSDs can be enhanced using nitrogen passivation, giving rise to n-type devices with excess free electrons.

In this work, we propose and theoretically investigate the use of fluorine and boron for passivation in order to realize complementary p-type graphene SSDs. Such devices would find applications in numerous circuit architectures including differential full-wave RF voltage multiplier cells for powering up flexible and implantable RF systems. Our quantum mechanical simulation results, based on the extended Huckel method and Nonequilibrium Green's function formalism, show that both boron and fluorine passivation result in a p-type device that rectifies in the third quadrant of its current-voltage characteristics, complementary to n-type graphene SSDs, which rectify in the first quadrant. Boron passivation gives rise to a device with enhanced rectification when compared with fluorine, achieving current rectification ratios in excess of 1000, similar to the n-type nitrogen passivated devices. Such a capability can open up the opportunity of realizing atomically-thin complementary graphene planar transistors with sub-10 nm dimensions. Such three terminal devices, based on the SSD architecture, are also proposed and investigated. We show preliminary results that prove the possibility of realizing atomically-thin complementary all-graphene planar transistors, which may find exciting applications in flexible, wearable and implantable electronics.

9668-153, Session 5A

Rapid assessment of live to dead bacterial cell ratios

Fang Ou, Rachel Guo, Cushla McGoverin, Simon Swift, Frédérique Vanholsbeeck, The Univ. of Auckland (New Zealand)

Determining the ratio of live to dead bacteria in a sample is important for the assessment of antibiotic efficacy, and cleaning procedures in both medical and food processing environments. Live to dead bacterial ratios are primarily determined by fluorescently staining the sample with two dyes of different colours, one of which is cell permeant and the other cell impermeant, e.g. SYTO 9 and propidium iodide. The sample is subsequently analysed using fluorescence microscopy or flow cytometry. Flow cytometry requires expensive instrumentation while fluorescence microscopic measurements may be time consuming. We are developing an all fibre based fluorometer, the optrode, for the measurement of fluorescence intensity of each cell-bound dye within a solution.

SYTO 9 and propidium iodide were added to Escherichia coli solutions with differing ratios of live to dead cells. Prior to recording fluorescence spectra samples were washed to remove unbound dye. The optrode consists of a 473 nm solid state laser, a DAQ controlled shutter, a 2x2 coupler, which directed laser light to a photodiode and to the sample. Collected light was passed through a 495 nm long pass filter to a spectrometer. Bound SYTO 9 intensity was ratioed to bound propridium iodide intensity and this parameter was correlated to live to dead bacterial cell ratios. We are investigating the impact of the sample preparation and the spectral bands used for analysis. Preliminary results are promising to show this method is applicable to the determination of live to dead cell ratios in a wide range of environments.

9668-106, Session 5B

Plasmonic, dielectric, and hyperbolic platforms for surface-enhanced spectroscopies *(Invited Paper)*

Stefan A. Maier, Imperial College London (United Kingdom)

Plasmonic nanostructures serve as the main backbone of surface enhanced sensing methodologies, yet the associated optical losses lead to localized heating as well as quenching of molecules, complicating their use for enhancement of fluorescent emission. Additionally, conventional plasmonic materials are limited to operation in the visible part of the spectrum. We will elucidate how nanostructures consisting of conventional and polar dielectrics can be employed as a highly promising alternative platform.

Dielectric nanostructures can sustain scattering resonances due to both electric and magnetic Mie modes. We have recently predicted high enhanced local electromagnetic field hot spots in dielectric nanoantenna dimers [1], with the hallmark of spot sizes comparable to those achievable with plasmonic antennas, but with lower optical losses. Here, we will present first experimental evidence for both fluorescence (Figure) and Raman enhancement in dielectric nanoantennas, including a direct determination of localized heating, and compare to conventional Au dimer antennas. The second part of the talk will focus on the mid-infrared regime of the electromagnetic spectrum, outlining possibilities for surface enhanced infrared absorption spectroscopy based on polar [2] and hyperbolic [3] dielectrics.

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9668-107, Session 5B

Sub-wavelength Si-based plasmonic light emitting tunnel junction

Volker J. Sorger, Hasan Goktas, The George Washington Univ. (United States)

Here we report on an experimental Silicon-based plasmonic light source that relies on tunneling electrons. The physical principle of light emission is based on inelastic scattering of hot electrons after tunneling through a thin insulating layer. This light-emitting tunnel junction utilizes combo cavity comprised of a photonic crystal nano-cavity and a sub-wavelength plasmon hybrid mode towards achieving enhanced light-matter-interactions. We demonstrate that the electro-luminescence efficiency is optimal for a metal thickness close to the skin-depth for visible and near infrared frequencies. Furthermore a grating increases the out-coupling efficiency by more than two orders of magnitude over a rough scattering metallic surface. Electrically this device is intriguing since the temporal modulation bandwidth is not capacitive limited, but depends on the tunnel barrier thickness. Thus, a THz fast modulation dynamic is expected from analyzing the tunnel current for sub 1-nm thin tunnel barriers. All measurements were carrier out by electrically driving the device under ambient conditions at room temperature. In conclusion, the demonstration of a Silicon-based light source with ultrafast modulation capability and minuscule footprint is shows potential for next generation on-chip sources for optical interconnect applications. However some intriguing questions are still open by the time of this paper submission such as experimentally verifying the modulation bandwidth, determining the wall-plug efficiency of the device, and we are positive to provide such details at the conference.

9668-108, Session 5B

Ultrafast generation and relaxation of non-equilibrium carriers in plasmonic nanostructures

Prineha Narang, Ravishankar Sundararaman, William A. Goddard III, Harry A. Atwater Jr., California Institute of Technology (United States)

Despite more than a decade of intensive scientific exploration, new plasmonic phenomena continue to be discovered, including quantum interference of plasmons, observation of quantum coupling of plasmons to single particle excitations, and quantum confinement of plasmons in single-nm scale plasmonic particles.

Simultaneously, plasmonic structures find widening applications in integrated nanophotonics, biosensing, photovoltaic devices, single photon transistors and single molecule spectroscopy. Decay of surface plasmons to hot carriers is a new direction that has attracted considerable fundamental and application interest, yet a theoretical understanding of ultrafast plasmon decay processes and the underlying microscopic mechanisms remain incomplete.

Recently we analyzed the quantum decay of surface plasmon polaritons and found that the prompt distribution of generated carriers is extremely sensitive to the energy band structure of the plasmonic material. A theoretical understanding of plasmon-driven hot carrier generation and relaxation dynamics at femtosecond timescales is presented here. We report the first ab initio calculations of phonon-assisted optical excitations in metals, which are critical to bridging the frequency range between resistive losses at low frequencies and direct interband transitions at high frequencies. We also present calculations of energy-dependent lifetimes and mean free paths of hot carriers, accounting for electron-electron and electron-phonon scattering, lending insight towards transport of plasmonically-generated carriers at the nanoscale. We will discuss calculations for multiplasmon and nonlinear processes in the ultrafast regime from the mid-IR to visible and in different geometries. Employing a Feynman diagram approach here has been critical to determine the relevant processes.

Finally we combine first principles calculations of electron-electron and electron-phonon scattering rates with Boltzmann transport simulations to predict the ultrafast dynamics and transport of carriers in real materials. In particular, we calculate the distributions of hot carriers generated by plasmon decay and their transport in aluminum and noble metal nanostructures. We also predict the evolution of electron distributions in ultrafast experiments on noble metal nanoparticles from the femtosecond to picosecond time scales, using a modified two-temperature model as well as a full time-dependent Boltzmann equation with ab initio collision integrals. We find that the positions of the d bands and the energy dependence of the electron-phonon matrix elements substantially alter the effective electronic heat capacity and electron-lattice coupling compared to previous simplified theoretical approaches and are important for interpreting high-power ultrafast optical measurements on plasmonic nanoparticles.

9668-109, Session 5B

Bright second harmonic generation of individual optical antennas by non-linear polarization phase engineering

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Recently, the capability to locally engineer the nonlinear optical response of ultra-confined light on nanostructures, including Second Harmonic Generation (SHG), has been a subject of extensive debate [1-6]. Numerous approaches, such as simultaneous enhancement of fundamental and harmonic fields [2,3], Fano interferences [4], hybridization [5] or phase control [6] have increased the efficiency of harmonic generations via strong field enhancement. However, obtaining strong far field intensities also requires efficient out-coupling of light from metallic nanostructures, which, can be trapped as dark excitations in the case of SHG. Yet, to our knowledge, there have been no studies on this aspect of the problem to date.

In this work, we demonstrate efficient out-coupling of SHG from a single nano antenna by engineering the nonlinear signal to emanate as "bright" radiation, from dipole active modes. Via thoughtful positioning resonant optical antennas at the SHG frequency around an antenna tuned to the fundamental, we demonstrate access to the phase of the non-linear surface polarization. In particular, using the same constituent particles in different configurations, we show how to activate and deactivate bright emission, which greatly affects SHG efficiency. This is clearly and important degree of freedom if we are to exploit the non-linear susceptibility of meta-materials. Using our technique, we obtain not only a dominant bright dipole SHG emission, but also the capability to control the output polarisation, inducing voluntarily linear, elliptically or circular polarised light. Furthermore, our experiments show clearly that SHG in individual optical antennas originates predominantly from non-linear surface, and not from the volume.

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9668-112, Session 5B

Fano coupling between Rayleigh anomaly and localized surface plasmon resonance and the sensor applications

Feifei Liu, Xinping Zhang, Beijing Univ. of Technology (China)

Fano coupling between Rayleigh anomaly and localized surface plasmon resonance is observed in aluminum grating structures, which are fabricated with the interference lithography in combination with vacuum evaporation. Using this method, localized surface plasmon resonance (LSPR) of aluminum nanoline is excited. The surface propagation mode of first- and second-order Rayleigh diffraction anomaly is strongly scattered and diffracted by the aluminum grating structures to the reflected light beam. The narrow-band and high signal-contrast diffracted light changes from peaks to sharp dips in the broad-band reflective optical extinction spectrum of plasmon resonance, which is recognized as a kind of Fano coupling. This kind of coupled mode is excellent sensitivity in refractive-index-sensor devices.

9668-132, Session 5B

Polarization-independent interference in inhomogeneous plasmonic nano-discs and nano-apertures

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Couplings effects in plasmonic systems consisting of a finite number of particles with nanoscale gaps have been widely described in terms of plasmon hybridization theory [1]. Meanwhile, couplings in periodic isolated nanoparticles with sufficiently large separations, like gratings or photonic crystals, have also been explained by phenomena like lattice modes, Wood's anomaly or the Talbot effect. But at intermediate separations among nanoparticles, none of these models can be applied to explain observed couplings [2].

In this work, we introduce two sets of plasmonic trimer nanostructures consisting of unequal nano-discs/apertures with varied separations. It is experimentally shown that at certain inter-particle separations, an intermediate radiative interference can be formed with a character distinct of those mediated by near-field and/or far-field radiative effects. Interestingly, its physical mechanism holds common features with light interference in Young's double/triple slit experiment. We demonstrate that regardless of the different resonance frequency of each component, both sets of structures are capable to exhibit Young-like resonances in spite of the different mechanisms of plasmonic interactions in holes and discs. Importantly, such trimers are designed and fabricated in such a way to obtain Young's resonances, entirely, independent of the excitation polarization leading to remarkable enhancements of absorption and scattering of light. Alongside this, our detailed study demonstrates that certain inter-particle distances, which induce Young's resonances in both systems, are purely dependent on the structural optical responses in vacuum, meaning that the environmental factors, such as substrate, do not impact it. These findings are particularly important for solar cells and bio-sensing applications.

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9668-222, Session 5B

Nonlinear optics with metasurfaces *(Invited Paper)*

Igal Brener, Sandia National Labs. (United States)

Many exciting fundamentals and applications have been demonstrated in linear optical phenomena arising from two-dimensional metamaterials, usually called metasurfaces. Very recently, interesting and sometimes surprising results have been obtained when optical metasurfaces are studied in the nonlinear regime. In this talk I will present some of these results for both metallic and dielectric metasurfaces. For example, record second order nonlinearities can be obtained when metallic metasurfaces are coupled with resonant transitions in semiconductors.

All-dielectric metasurfaces provide a platform to engineer magnetic and electric resonant modes in wavelength-scale nanoresonators with very low loss. Fabricating such dielectric metasurfaces from different types of semiconductors can be used to enhance their second and third order nonlinearities by orders of magnitudes.

9668-113, Session 5C

Micro-imaging cancer by parametric and multimodal extensions of optical coherence tomography *(Invited Paper)*

David D. Sampson, The Univ. of Western Australia (Australia)

Tools to image cancer in vivo are important for biological and biomedical research based on animal models, and also important for next-generation diagnosis and surgical guidance in the medical setting. Whilst advanced confocal and multiphoton microscopy continue to make advances on the cellular scale, and medical imaging tools, such as positron emission tomography and magnetic resonance imaging, are well established on the scale of the whole tumor and organ, imaging the tumor environment on the micro-scale, between that of cells and whole tissues, is currently challenging.

Our group has been exploring the potential of optical coherence tomography for imaging cancer in whole tissues, on the resolution scale of 2-20 m and over fields of view in the range 1-50 mm per dimension. We have been developing the capacity to perform such imaging using hand-held probes and from within a hypodermic needle, which can be delivered to locations deep in tissues not normally accessible to optical imaging.

The intrinsic contrast provided by tissue scattering reveals many morphological features of tumors, but is, frequently, insufficient. For example, it does not readily reveal microvasculature, and it can be difficult to distinguish malignant tumor from uninvolved stroma. We have been developing a range of advances aimed at improving the basic optical coherence tomography approach. These include speckle decorrelation to image tissue microvasculature and parametric approaches that extract, from a three-dimensional optical coherence tomography data set, a two-dimensional image of an optical parameter, such as attenuation or birefringence, or extract a mechanical parameter, e.g., stiffness. The combination of these approaches promises a comprehensive means of characterizing the tumor microenvironment.

9668-114, Session 5C

Laser scribed graphene oxide film with fractal structures

Litty V. Thekkekara, Swinburne Univ. of Technology (Australia)

Cost effective and high performance, energy storage are essential for over-coming the electricity crisis of the modern world. Recent one-step scalable approaches for producing micro-patterned planar electrodes using laser scribed graphene oxide film for supercapacitors [1, 2] is a promising direction towards this achievement without the requirement of extra foot-print. Here we report, an improved laser scribed supercapacitor performance using new design based on fractal structures. Fractals are self-repeating units that lead to the decrease of the mean ion free path of the electrolyte ions between the electrodes which leads to the overall improvement of the performance of energy storage.

Direct patterning of the micro-electrodes in the drop-casted graphene oxide (GO) film was conducted using the CO2 continuous wave laser beam at 10.6 μm which resulted in the photo-thermal reduction of GO film. An ionogel electrolyte containing fused silica and ionic liquid [BMIM] [NTF2] with an electrochemical window of 2.5 V was used in this study. The obtained fractal supercapacitor had a two order of magnitude increase in the capacitance compared to its planar micro-electrode counterpart. This kind of novel designs in combination with advanced laser writing facilities shows the potential to overcome the major drawback of supercapacitors as lower energy density.

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9668-115, Session 5C

Development of the magnetic force-induced dual vibration energy hervester using a unimorph cantilever

Motomitsu Umaba, Yusuke Morita, Eiji Nakamachi, Doshisha Univ. (Japan)

In this study, a high frequency piezoelectric energy harvester converted from the human low vibrated motion energy was newly developed. This hybrid energy harvester consists of the unimorph piezoelectric cantilever, the pendulum and a pair of permanent magnets. One magnet was attached at the edge of cantilever, and the counterpart magnet at the edge of the pendulum. The mechanical energy provided through the human walking motion, which is a typical ubiquitous existence of vibration, is converted to the electric energy via the piezoelectric cantilever vibration. At first, we studied the energy convert mechanism and analyze the performance of novel energy harvester, where the resonance free vibration of unimorph piezoelectric cantilever generated a high electric power. Next, we equipped the counterpart permanent magnet at the edge of pendulum, which vibrates with a very low frequency caused by the human walking. Then the counterpart magnet was set at the edge of unimorph piezoelectric cantilever, which vibrated with a high frequency. This low-to-high frequency convert "dual vibration system" can be characterized as an enhanced energy harvester. We fabricated two types of vibration systems, which had the vertical and parallel vibration planes of unimorph piezoelectric cantilevers against the vibration plane of the pendulum. We examined and obtained maximum values of voltage and power in this system, as 1.2 V and 1.2 ?W. Those results show the possibility to apply for the energy harvester in the portable and implantable Bio-MEMS devices.

9668-143, Session 5C

CMOS compatible fabrication process of MEMS resonator for timing reference and sensing application

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For many years, electromechanical resonators such as crystal resonator, ceramic resonator are the ultimate choices for the designs of timing and frequency reference in all electronic systems. This tendency will probably keep going for many more years. However, current market demands for small size, low power consumption, cheap and reliable products, has divulged many limitations of this type of resonators. They cannot be integrated into standard CMOS (Complement metal-oxide-semiconductor) IC (Integrated Circuit) due to materials and fabrication processes incompatibility. Currently, these devices are off-chip and they require external circuitries to interface with the ICs. This configuration significantly affects the overall size and cost of the entire electronic system. In addition, any external connection, especially at high frequency, will potentially create negative impacts on the performance of the whole system due to signal degradation and parasitic effects. Furthermore, due to off-chip packaging nature, these devices are usually quite expensive, particularly for high frequency and high quality factor devices, and therefore they can significantly increase the overall cost of the final product. To address these issues, researchers have been intensively studying on an alternative for this type of resonator utilizing the new emerging MEMS (Micro-electro-mechanical systems) technology.

This paper reports on a design and fabrication of a low cost, high frequency and a high quality MEMS resonator, which can be integrated into a standard CMOS IC. This device is expected to operate in hundreds MHz range, quality factor surpasses 10000 and series motional impedance low enough that could be matching into conventional system without enormous effort. The potential uses of this device in timing reference and sensing applications will also be discussed.

9668-148, Session 5C

Customization of BCP Lo for directed self assembly

Mary Ann J. Hockey, Brewer Science, Inc. (United States)

Brewer Science Inc. has developed tunable high chi BCP materials with surface energy matching a library of random copolymer brush layers. A series of BCP formulations were synthesized using the approach of enhancing the PS block of the BCP material with selective monomers. We achieved L0 values ranging from standard 28 nm to high chi results measuring L0 values of 14-16 nm. Our BCP materials can be easily tuned to achieve a wide range of L0 values using selective monomer control techniques. In addition to the high chi properties, our material selection has significant advantages in that no topcoat or solvent annealing was required for alignment of BCPs inside chemoepitaxy guide structures. We achieved 7x multiplication factor within a pitch of 112 nm spaces having 20 nm wide XMAT guides. At dimensions for line geometries in the 7-8 nm range, using Brewer Science Inc. BCP plus selective neutral layer brush combinations, anneal conditions were 160˚-180˚C at 5 minutes for best-case alignment. All modified PS BCP formulations were coated directly onto either “brush” layers or an optional multifunctional (hard mask neutral layer) HM NL for direct comparisons with good results.

9668-210, Session 5C

Nano-engineered flexible pH sensor for point-of-care urease detection

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Accurate pH monitoring is crucial for many applications, such as, water quality monitoring, blood monitoring, chemical and biological analyses, environmental monitoring and clinical diagnostic.

The most common technique for pH measurement is based on the use of conventional glass pH electrodes. Glass electrodes have several limitations, such as mechanical fragility, large size, limited shapes and high cost, making them impractical for implementation as Lab-on-chips and pH sensor capsules.

Various metal oxides, such as RuO2, IrO2, PtO2, RhO2, TiO2, SnO2, Ta2O5 and PdO have recently been proposed for the realization of pH sensing electrodes. Specifically, ruthenium oxide exhibits unique properties including thermal stability, excellent corrosion resistance, low hysteresis high sensitivity, and low resistivity.

In this paper, we demonstrate the concept of a miniaturized ion selective electrode (ISE) based pH sensor for point-of-care urease monitoring. The sensor comprises a thin film RuO2 on platinum sensing electrode, deposited using E-beam and R.F. magnetron sputtering, in conjunction with an integrated Ag/AgCl reference electrode. The performance and characterization of the developed pH/urease sensors in terms of sensitivity, resolution, reversibility and hysteresis are investigated. Experimental results show a linear potential-versus-urease-concentration response for urease concentrations in the range 0 - 1.8 mg/dL. Experimental results demonstrate super-Nernstian slopes in the range of 64.33 mV/pH - 73.83 mV/pH for RF sputtered RuO2 on platinum sensing electrode using a 80%:20% Ar:O2 gas ratio. The RuO2 sensor exhibits stable operation and fast dynamic response, making it attractive for in vivo use, wearable and flexible biomedical sensing applications.

9668-223, Session 5C

Investigation on surface enhanced Raman spectroscopy for ultrasensitive diagnosis of malaria infection

Quan Liu, Keren Chen, Nanyang Technological Univ. (Singapore)

No Abstract Available

9668-120, Session 6A

Rethinking microscopy along the cost and efficiency axis *(Invited Paper)*

Changhuei Yang, Xiaoze Ou, California Institute of Technology (United States)

The standard microscope is unique amongst many other inventions of its era, such as the slide rule and pendulum clock, in that it is an ever more vital technology. However, its tried-and tested design is imposing significant throughput and cost limitations on modern medicine. I will discuss my group’s recent work on rethinking microscopy from the ground up with the help of high-tech and cheap consumer devices, such as cellphone cameras and graphic processing units. I will report on a self-imaging lensless petri dish technology (ePetri) that is capable of streaming microscopy-level live cell culture images directly out of the incubator. I will also discuss our recent work on Fourier Ptychographic Microscopy - a computational microscopy method that enables a standard microscope to push past its physical optical limitations to provide gigapixel imaging ability.

9668-149, Session 6A

Liquid marble as microbioreactor for bioengineering applications

Peggy P. Chan, Swinburne Univ. of Technology (Australia)

Liquid marbles are new type of miniature bioreactors that facilitate production and culture of cell spheroids in vitro due to the constrained internal structure of liquid marbles, along with their non-adhesive shell [1]. In this study, we investigate the use of the liquid marble as a microbioreactor to produce embryoid bodies (EBs) from stem cells, and subsequent differentiation into cardiomyocytes. Liquid marble micro-bioreactors were prepared by inoculating embryonic stem cells (ESCs) onto a bed of hydrophobic particles. ESCs aggregated to form uniform EBs after inoculation [2]. Without the addition of growth factors, suspended EBs from liquid marbles express various precardiac mesoderm markers including Flk-1, Gata4, and Nkx2.5. These results indicate that liquid marble provides a suitable microenvironment to induce EB formation and spontaneous cardiac mesoderm differentiation. Some of the EBs are subsequently plated, the plated EBs express mature cardiac markers atrial myosin light chain 2a (MLC2a) and ventricular myosin light chain (MLC2v), and the cardiac structural marker ?-actinin. The majority of the plated EB further differentiated into contractile cardiomyocytes, indicating that these EBs have differentiated into functional cardiomyocytes. The contraction of cardiomyocytes was synchronized with longer time in culture [3].

The liquid-marble method was found to be advantageous for EB formation as it is cost effective and simple; it also allows larger scale EB production compared with conventional hanging drop method [3]. Overall, this study shows that liquid marbles can serve not only as a novel platform to induce the formation of EBs but also to facilitate cardiogenesis. The cardiomyocytes generated via this liquid marble strategy could provide a continuous source of donor cardiomyocytes for cell replacement therapy in damaged hearts. Furthermore, this technology would be highly beneficial to provide cardiomyocytes for use in cardiac drug discovery programs and safety testing. Since the quantity of cells required for the above-mentioned applications is very high, it becomes imperative to develop defined and efficient in vitro protocols, which would then provide the stringent levels of safety and quality control making stem cell transplantation therapy realizable. Our

study provides a step-up this ladder and gives a new promise and hope in cardiovascular research [3].

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9668-154, Session 6A

A temperature-compensated optical fiber force sensor for minimally invasive surgeries

Zonglai Mo, Peter Xu, Neil G. R. Broderick, The Univ. of Auckland (New Zealand); Hao Chen, The University of Auckland (New Zealand)

Force sensing in minimally inversive surgery (MIS) is a chronic problem since it has an intensive magnetic resonance (MR) operation environment, which causes a high influence to traditional electronic force sensors. Optical sensor is a promising choice in this area because it is immune to MR influence. However, the changing temperature introduces a lot of noise signals to optical sensors, which is the main obstacle for optical sensing applications in MIS. This paper proposes a miniature temperature-compensated optical force sensor by using Fabry-Perot interference (FPI) principle. This FPI based force sensor is designed for identifying tissue types during MIS by analysing insertion forces for tools' tips. It can be integrated into medical tools' tips to detect the tip force feedback. The temperature noise is decreased by using another reference FPI sensor, which will not bear the applied force, to provide temperature information. The FPI sensor with a 400um outer diameter is fabricated and integrated into the tip of an injection needle with 1mm inner diameter by using epoxy. The designed temperature compensated structure is simulated first on the computer by using finite element analysis software. After fabrication, it is calibrated by using a special designed mechanical force applied platform with a dynamic electronic force sensor and a temperature control system, and then followed by insertion experiments. The results comparison between simulation and experiment is carried out. The sensor's capability of identifying tissue types is also tested by insertion experiments using a silicon rubber skin phantom.

9668-155, Session 6A

Self-assembled laser-activated plasmonic substrates for high-throughput, high-efficiency intracellular delivery

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Delivering material into cells is important for a diverse range of biological applications, including gene therapy, cellular engineering and imaging. We present a plasmonic substrate for delivering membrane-impermeable material into cells at high throughput and high efficiency while maintaining cell viability. The substrate fabrication is based on an affordable and fast colloidal self-assembly process. When illuminated with a femtosecond laser, the light interacts with the electrons at the surface of the metal substrate, creating localized surface plasmons that form bubbles via energy dissipation in the surrounding medium. These bubbles come into close contact with the cell membrane to form transient pores and enable entry of membrane-impermeable material via diffusion. We use fluorescence microscopy and flow cytometry to verify delivery of membrane-impermeable material into HeLa CCL-2 cells. We show delivery efficiency and cell viability data for a range of membrane-impermeable cargo, including dyes and biologically relevant material such as siRNA. We estimate the effective pore size by determining delivery efficiency for hard fluorescent spheres with diameters ranging from 20 nm to 2 um. To provide insight to the cell poration mechanism, we relate the poration data to pump-probe measurements of micro- and nano-bubble formation on the plasmonic substrate. Finally, we investigate substrate stability and reusability by using scanning electron microscopy (SEM) to inspect for damage on the substrate after laser treatment. SEM images show no visible damage. Our findings indicate that self-assembled plasmonic substrates are an affordable tool for high-throughput, high-efficiency delivery of material into mammalian cells.

9668-219, Session 6A

Sub-bandage sensing system for remote monitoring of chronic wounds in healthcare

Alex J. Hariz, Nasir Mehmood, Nico Voelcker, Univ. of South Australia (Australia)

Chronic wounds, such as venous leg ulcers, can be monitored non-invasively by using modern sensing devices and wireless technologies. The development of such wireless diagnostic tools may improve chronic wound management by providing evidence on efficacy of treatments being provided. In this paper we present a low-power portable telemetric system for wound condition sensing and monitoring. The system aims at measuring and transmitting real-time information of wound-site temperature, sub-bandage pressure and moisture level from within the wound dressing.

The system comprises commercially available non-invasive temperature, moisture, and pressure sensors, which are interfaced with a telemetry device on a flexible 0.15 mm thick printed circuit material, making up a light-weight biocompatible sensing device. The real-time data obtained is transmitted wirelessly to a portable receiver which displays the measured values. The performance of the whole telemetric sensing system is validated on a mannequin leg using commercial compression bandages and dressings. A number of trials on a healthy human volunteer are performed where treatment conditions were emulated using various compression bandage configurations.

A reliable and repeatable performance of the system is achieved under compression bandage and with minimal discomfort to the volunteer. The system is capable of reporting instantaneous changes in bandage pressure, moisture level and local temperature at wound site with average measurement resolutions of 0.5 mmHg, 3.0 %RH, and 0.2 ºC respectively. Effective range of data transmission is 4-5 m in an open environment.

9668-38, Session 6B

Plasmonic nanoparticle-based SERS immunosensor-on-a-chip

Lim Wei Yap, Wenlong Cheng, Monash Univ. (Australia); Yonggang Zhu, Commonwealth Scientific and Industrial Research Organisation (Australia)

Synthetic progress in wet chemistry synthesis of plasmonic nanoparticles provides a rational route to engineer their sizes and shapes, formulating so-called plasmonic periodic table. [1] Control over self-assembly of these plasmonic atoms allows for fabrication of unique SERS substrates which are soft and elastic enabling direct identification of chemicals sitting on topologically complex surfaces [2-3] or satellite SERS particles [4-5]. Here, we presented a multifunctional Fe_3O_4@AuNPs@Ag core-satellite-shell nanoparticles which can be used for immunosensing in a microfluidic chip.

The multifunctional SERS-active particles were designed and synthesized in the Cheng's NanoBionics lab at Monash University. Then the nanoparticles were applied for a biosensing in a microfluidic platform developed at CSIRO Microfluidic lab. The core-satellite nanoparticles, immunoglobulins and Raman reporter-labelled gold

nanoparticles were mixed in the microfluidic device. Experiments conducted on this nanoparticles indicate that the Raman signal enhancement greatly contributed to high sensitivity of our immunosensing system. With extensive tuning on silver coating thickness plasmonic particle size, fluid flow and mixing conditions, these particles were demonstrated to achieve low limit of detection of Immunoglobulin G antibody (100fg/ml) in a microfluidic device.

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9668-111, Session 6B

Tunable photoluminescence of two-dimensional MoSe2 by gold nanoantennas

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Two-dimensional transition metal dichalcogenides (TMDCs) show a great potential for optoelectronic applications due to their unique properties, including electrically controlled photoluminescence (PL), strong spin-valley coupling, piezoelectricity, and nonlinearity. TMDCs have also been employed as single-photon emitters, however the control of their emission through coupling to nanoantennas remains largely unexplored. Importantly, antenna-TMDCs coupling is an effective way for PL control due to the high Purcell enhancement near the plasmonic nanostructures. MoSe2, a member of the TMDCs family, is an important candidate for coupling to plasmonic structures due to its smaller bandgap and higher electron mobility in comparison to the readily used MoS2. The PL of MoSe2 in the near-infrared is also more appropriate for plasmonic applications as it remains away from the interband transition of gold.

Here we study the interaction between monolayer MoSe2 and plasmonic dipolar antennas demonstrating efficient control of the PL from the TMDC layer. In our experiments, we transfer an exfoliated monolayer MoSe2 onto an array of rectangular gold nanoantenna whose plasmonic resonances overlap with the PL emission of the material. By varying a thickness of the spacer between the MoSe2 layer and the nanoantenna, we demonstrate tunable PL from threefold enhancement (sample with spacer) to twice quenching (sample without spacer). Furthermore, the observed PL from the TMDC-antenna system demonstrates polarization-dependent properties, thus offering the possibility of polarization-based PL control. To the best of our knowledge, this is the first study of Au-MoSe2 plasmonic hybrid structures realizing flexible PL manipulation, which is promising for future optoelectronic applications.

9668-125, Session 6B

Hybrid thermodynamics for hydrogen in palladium nanocubes and nanoparticles for active plasmonics *(Invited Paper)*

Nikolai Strohfeldt, Univ. Stuttgart (Germany); Ronald Griessen, VU Univ. (Netherlands); Harald Giessen, Univ. Stuttgart (Germany)

Palladium-hydrogen is a prototypical metal-hydrogen system, which is well suited for active plasmonics. Upon hydrogenation of Pd to PdHx, it is possible to change the dielectric function and hence the plasmonic resonance1–3. Recently, also materials such as Yttrium and Magnesium have shown such properties4,5. It is therefore not at all surprising that a lot of attention has been devoted to the ab- and desorption of hydrogen in nanosized plasmonic palladium particles. Here, we show that the large body of data available so far in literature6–10 exhibits general patterns that lead to unambiguous conclusions about the detailed microscopic processes involved in H absorption and desorption in Pd nanoparticles that can be used as prototypes for active plasmonic elements. On the basis of a remarkably robust scaling law for the hysteresis in absorption-desorption isotherms, we show that hydrogen absorption in palladium nanoparticles is consistent with a coherent interface model and is thus clearly different from bulk Pd behavior. However, H desorption occurs fully coherently only for small nanoparticles (typically smaller than 50 nm) at temperatures sufficiently close to the critical temperature. For larger particles it is partially incoherent as in bulk, where dilute ? PdHx and high concentration ?-PdHx phases coexist. In support of these conclusions, we developed a model that is able to reproduce all the essential features of the thermodynamics of H in Pd nanoparticles over a wide range of sizes (from a few nm up to hundreds of nm) as long as no dislocations are generated in the core of the particles.

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9668-126, Session 6B

Waveguide-plasmon-polariton enhanced photochemistry

Daniel E. Gomez, Commonwealth Scientific and Industrial Research Organisation (Australia)

One key process in plasmon-enhanced photocatalysis is the transfer of hot charge-carriers from metal nanostructures into photocatalytically active materials.

This process is secondary to the initial step of light absorption by the metal nanostructures.

Light absorption in these structures can be controlled by designing complex geometries with tailored optical cross--sections.

Here we present a study on one of the simplest nanostructures exhibiting plasmon resonances: one-dimensional gratings of metal wires.

We present results on the effect of the periodicity of these arrays on the resonant absorption of light and on the hot charge-carrier transfer to a supporting TiO_2 thin film.

This charge transfer process is monitored by following the photocatalytic decomposition of small organic molecules in solution.

We find strong enhancements in the rate of decomposition that exhibit a correlation with the measured optical extinction spectra of the plasmonic nanostructures.

9668-127, Session 6B

Plasmonic nanorod antennae for enhanced photo-acoustic interaction

Ivan S. Maksymov, Andrew D. Greentree, RMIT Univ. (Australia)

Plasmonic antennae made of single metallic nanoparticles or their constellations have attracted enormous attention because they offer novel opportunities to control light at the scale smaller than the wavelength of light [1]. Many plasmonic antennae consist of single metal nanoparticles such as nanorods and they support dipole-like resonances. However, nanorods with a large (>10) aspect ratio can also support higher-order resonances. These resonances originate from plasmon standing waves excited in metal nanorods by an electric field of incident light and they often have asymmetric lineshapes typical of a Fano resonance [2]. Lower radiative losses of the higher-order modes lead to higher local field confinement attractive for many applications including solar energy harvesting, sensing, and enhanced spectroscopy.

We conduct self-consistent rigorous numerical simulations of nonlinear acoustic wave interaction in liquids and of light scattering from the fundamental and nonlinear generated acoustic waves. We demonstrate that the intensity of Brillouin peaks is strongly enhanced by an ultra-small nanorod plasmonic antenna. The obtained spectrum resembles a Brillouin frequency comb [3] with the intensity of the individual spectral components given by the intensity of the nonlinear harmonics of the acoustic waves. We suggest that the spectral composition of this frequency comb can be controlled by tailoring the nonlinear acoustic interaction of two and more acoustic waves of different frequency.

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9668-128, Session 6B

Transforming polarisation to wavelength via two-colour quantum dot plasmonic enhancement

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Optical nano-antennas have become a hot topic in photonics research recently due to their ability to manipulate electromagnetic radiation at subwavelength scale. Of particular interest is the application of optical nano-antenna to enhancement of quantum sources, such as semiconductor Quantum Dots (QD) and nano-diamond Nitrogen Vacancy (NV) centers. Much like their Radio Frequency (RF) cousins optical nano-antennas are able to enhance and direct radiation from a localized source in the near-field of the antenna to the far-field. This work exploits RF antenna designs by applying them to the design of optical nano-antennas for enhancement of multiple semiconductor QDs. In particular the Vee antenna design, commonly used in improvised military RF applications, is utilised in this work as an optical nano-antenna to enable the selective excitation of two different colour QDs via polarization control.

The Vee antenna has two bright resonant modes in the visible spectrum, typically spectrally separated by 100nm (~500nm and 600nm resonant wavelength), which are excited by orthogonal polarisations. Via quantum source enhancement by the Vee antenna, two different colour QDs can be enhanced selectively by the polarization of the excitation source. The Vee antennas are fabricated with E-beam Lithography using aluminium as the antenna material and glass as the substrate. The Vee antenna design consists of two dipole antennas, (90?30nm, thickness of 30nm) orientated at 90 degrees to each other, where the gap between the antennas is used to tune the spectral seperation of the two orthogonal resonances. The greatest QD enhancement is achieved by locating the QDs in the gap between the two arms, where the electric field is its greatest for the two different plasmonic resonances of the antenna. An experimental investigation into the polarisation selective excitation of two distinct QDs by Vee antennas will be presented, along with a study into physical design of the antennas to achieve the desired optical response.

9668-129, Session 6B

Electrostatically assembled gold nanolens arrays for enhanced nearfield focusing

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Nanoscale gold structures such as gold nanoparticles (AuNPs) have unique properties which can be used to improve the light harvesting abilities of solar cells, enhance catalytic processes and also for high efficient sensors. These applications take advantage of the plasmonic near field enhancement of AuNPs.[1,2] This effect is particularly strong and focused when two nanoparticles are only separated by a narrow gap. A variety of structures have been studied theoretically and nanolenses have been developed. Lithographic methods have been used to produce different nanolenses and their focusing effects have been proven,[3] however, simpler methods with the possibility to create bigger arrays of these structures are needed.

In this project we present a wet chemical approach for the fabrication of such arrays. Substrate and AuNPs are functionalised with molecules that confer electric charge. The parameters that allow the control of this stepwise electrostatic assembly will be discussed. A funnel like gradient of the interaction energy can be created to guide the particles to the desired adsorption positions. The gaps between individual particles vary between 1 and 2 nm. Plasmonic properties and performance of the final structures are investigated in experiment and theory (boundary element method approach[4]).

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9668-131, Session 6B

Tunable Tamm plasmon modes as high sensitivity bioensors

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A plasmon state formed at the boundary of photonic crystal and metal is experimentally testified. In analogy with the electronic Tamm states formed at the boundaries of a crystal, the plasmon state is named Tamm plasmon (TP). Different from the well-known surface plasmon, the propagation constant dispersion of TP lies within the light corn. Consequently, no coupling system, like prism, is required to excite the plasmon mode. In addition, both TE and TM polarized light can be employed to excited TP. Studies of TP based application and its tunability were intensively discussed. However, the mechanism behind resonance wavelength (?TP) shifting and variation of energy coupling efficiency to resonance modes has been less studied. In addition, a systematic approach to design TP resonances at specific wavelengths and to optimize the coupling efficiency remains unstudied. In this work, a novel approach based on admittance loci is proposed to analyze the TP resonance modes and further design the layer structure for shifting resonance wavelength and tuning the coupling efficiency. In this work, the several different types of Tamm plasmon will be presented, including dielectric multilayers-metal, liquid crystal-metal, and colloidal spheres-metal interface. The function of sensors in the TP design is also demonstrated.

9668-133, Session 6B

Plasmonic nano-resonator enhanced one-photon luminescence from single gold nanorods

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Photoluminescence from a noble metal nanoparticle promises important applications in various area and is of interest in the fundamental physics as well. However, the mechanism of the photon luminescence from metallic nanostructures remains a subject of debate. Different from previous thermal radiation, this work observed the coherent anti-Stokes and Stokes photonluminescence from a single gold nanorod under a cw laser excitation. We found that the spectral profile of the anti-Stokes emission is essentially different from that of the Stokes emission. Based on our experimental measurement, We model the photoluminescence from single gold nanorods as the emission from a local surface plasmonic resonance mode. This theoretical model provides a self-consistent and unified understanding for both the anti-Stokes and Stokes emission. Our theory agrees well with all our experimental observation and also provides a good explanation for the main features of previous experimental observations, e.g. the enhanced quantum yield,the saturation and the shape dependence of the one-PL from noble metal nanoparticles.

9668-134, Session 6B

Multipolar plasmon resonances on opto-capacitive nano-structures

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Silver is considered as one of the most desirable materials for plasmonic devices due to it having low loss (low ?2) across the visible spectrum. Interestingly, silver nanoparticles are able to self-assemble into complex shapes like base-to-base or tip-to-tip triangles or stacks. While the optical properties of tip-to-tip dimers of nano-triangles have been quite intensively studied, the geometric inverse, the base-to-base configuration, has received much less attention. Here we report the results of a computational study of the optical response of structures comprised of individual and paired triangular silver nano-prisms ('nano-triangles'). Calculations were performed using the discrete dipole approximation [1]. The effect of varying the gap size for a base-to-base dimer of 80?80?80?20 nm Ag nano-triangles, in vacuum and on a glass substrate, are considered.

The results indicate that the base-to-base configuration can sustain strong multimode resonances. The pairing of the parallel triangle edges produces a strongly capacitive configuration and very intense electric fields over an extended volume of space. The base-to-base configuration could be suitable for a range of plasmonic devices, such as sensors based on metal-enhanced fluorescence or surface enhanced Raman spectroscopy, that require a strong and uniform concentration of electric field.

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9668-135, Session 6B

Opto-mechanical interactions in split ball resonators

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We demonstrate that a gold split-ball resonator(SBR) in the form of a spherical nanoparticle with a nanocut along the radius supports optical magnetic and acoustic modes. Both modes are strongly co-localised near the cut, enabling strong opto-mechanical interactions. Moreover, the strength of the interaction can be further enhanced by the high quality factor of the acoustic eigen-mode around 1000 which predominantly originates from the acoustic wave radiation loss to air since the acoustic mode localisation away from the bottom suppresses the anchor loss and the dynamic viscosity induced intrinsic loss.

Due to the strong opto-mechanical interaction, the optical resonance mode induced force can efficiently drive the acoustic vibration. For demonstration purpose, we simulate the excitation of the acoustic vibrations through laser heating induced by the optical magnetic resonance, and determine that a laser pulse which gives 100K temperature change in a SBR of 100 nm radius and 15 nm wide nanocut induces the oscillation of the two lobes at the opposite sides of the cut at the acoustic eigen frequency resulting in the cut width deformation of 200 pm. Such deformation modifies SBRs' scattering response by 0.05%pm-1 and can lead to very significant change of 10% in total optical scattering.

Such strong opto-mechanical coupling in SBRs suggests promising applications such as surface-enhanced Raman spectroscopy and detection of localised strain.

9668-136, Session 6B

Integrate plasmonic nanoantennas for polarisation sensitive directional waveguide coupling

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In the last decade, plasmonic nanoparticles and nanoantennas have proven to provide unprecedented opportunities to control and guide light at the sub-wavelength scale. Due to their unique ability to confine and enhance light to subwavelength volumes, they provide a basis for directional scattering of light into and out of waveguides and, therefore, can also be utilized as a new type of optical coupler between free-space and integrated waveguides. However, integrated waveguide-couplers that are sensitive to and make use of different waveguide modes are still widely unexplored.

Here, we suggest and realise the plasmonic nanoantenna that couples two orthogonal polarisations of light from free space into two different waveguide modes (TE and TM) of an optical waveguide. Importantly, the antenna couples the two modes in opposite directions of the waveguide, enabling simulateneously subwavelength polarisation splitting on a chip. More specifically, we realise a plasmonic nanoantenna operating at 1550 nm with an area below 0.2 ?m2 and integrate it onto a single-mode silicon waveguide. This compact element can provide a front-to-back ratio of over 20 both for TE- and TM-mode-light propagation in the waveguide. Furthermore, we experimentally measure the ultrafast optical response of the polarisation-splitting device with a 10 Gbit/s on-off keying modulated at 1550 nm wavelength. We obtain under 10-9 bit error rate with negligible signal degradation. Based on these results, our integrated plasmonic antenna provides promising new opportunities for on-chip nano-scale polarisation splitting with applications in polarisation dependent signal processing, coherent detection, as well as in integrated plasmonic bio-photonic sensing.

9668-116, Session 6C

Fabrication of plasmonic photonic crystals using photo-reduction of metallic ions in patterned polymer film

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A new approach is proposed to achieve plasmonic photonic crystals through photoreduction of silver ions and subsequent annealing process, where the silver ions were doped in polymer films that were patterned by template photoresist (PR) gratings. The template grating with a period of 300 nm was fabricated on an ITO-coated silica substrate through interference lithography. The mixed aqueous solution of silver nitrate and poly (vinyl pyrrolidone) (PVP) was then spin-coated on the PR grating structures. Due to the natural confinement by the PR grating, most of silver ions were located within the grating grooves instead of on the surface of the grating lines. After being irradiated by a single UV laser beam at 325 nm for about 70 min, the silver ions were reduced and aggregated to silver nanoparticles. The irradiated sample was then rinsed in ethanol and acetone, respectively, removing the remaining polymer and the template photoresist grating. After the annealing process, the silver nanoparticles were melted and fused into continuous nanolines. Strong Fano-coupling between the plasmonic and photonic resonance modes was measured, which verifies success of this fabrication technique.

9668-118, Session 6C

Freestanding metal nanomembranes with nanohole arrays patterned by a template transfer method

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Freestanding nanomembranes have been a research interest for several decades since they combine nanoscale thickness and features with macroscopic lateral dimensions at the same time. Several cutting-edge freestanding ultrathin membranes made by inorganic matter (i.e. silicon, metals, nanoparticles, graphene, PDMS), organic materials (i.e. epoxy resin) and hybrid composite have been implemented. These freestanding membranes are emerging as critical elements in various sensing devices, such as mechanical, chemical and thermal sensors. For plasmonic sensing, freestanding metal membranes as miniature passive plasmonic sensors are highly desirable as they can be attached to unconventional substrates incompatible to conventional fabrication methods. To date, several techniques have been achieved for the fabrication of freestanding nanoscale membranes, including spin-coating, layer-by-layer assembly, and monolayer self-assembled. However, these approaches are not applicable to metal. The synthesis of large-area freestanding metal nanomembranes with submicron features is still a challenge and remains to be explored.

Here, we report a new fabrication technique that combines the template transfer method and chemical etching, capable of fabrication of large-area freestanding metal nanostructures with various features. The created nanomembrane in ~100 nm thickness features a periodic nanohole array with high quality and uniformity over a large area. In comparison to the same nanohole array on a substrate, the freestanding nanohole array shows much higher transmission efficiency, which would enhance the plasmonic sensing performance. Characterization of our freestanding nanomembrane revealed mechanical and electrical properties, which enable the nanomembrane to serve as plasmonic transducer, filter and substrate.

9668-119, Session 6C

Spectroscopic behavior in whispering-gallery modes by edge formation of printed microdisk lasers

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Whispering-gallery modes (WGMs) microcavities becomes more and more remarkable in lately researches. The spectral behavior (resonating wavelength) of the WGM microcavities is an important factor for the analysis and the applications, however, dynamically control of the spectral properties is difficult except temperature and refractive index modification in environment. Recently, we found the peak wavelength shifts on WGM by increasing pumping intensity from some of our newly "printed" polymeric microdisk lasers. In this paper, the interaction between lasing wavelength and formations of microdisk will be studied. In the experiment, Rhodamine 6G dye-doped microdisks, with the diameter about 75 μm, of two different edge formations ((i): thick and rounded edge of microdisk, (ii): thin and sharpened edge of microdisk) were presented to WGM lasing. The microdisks fabricated by "ink-jet printing method". By pumping with an frequency-doubled and Q-switched Nd:YAG laser, the WGM lasing could be achieved with comb shaped spectrum around the wavelength of 600 nm. The lasing spectrum in disk (i) showed very smaller shift with increasing the pumping fluence. On the other hand, the lasing spectrum disk (ii) was shifted by 1 nm to shorter wavelength. Only the shifts in (i) can be understood by the anomalous dispersion caused by the optical gain in Rhodamine 6G doped polymer. Our analysis can explain that the extra-shifts in (ii) is due to the "to-center-shift" on WGM caused by the interaction between the sharpened edge and the increased optical gain.

9668-138, Session 6C

Tunable focusing by elastic metasurface

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Metasurfaces are functional two-dimensional structured arrays of elements that can manipulate reflected and transmitted waves in an almost arbitrary way. The elements of such metasurface are often made in the form of subwavelength resonators that control both amplitude and phase of electromagnetic fields. The concept of metasurfaces opened up new avenues for modifying amplitude, polarization and direction of light propagation. In this work we propose a focusing reflector designed in the form of a flat metasurface with an elastic substrate. The focal length of this reflector can be tuned on demand by stretching the elastic material which hosts the resonators. Our metasurface is formed by electric resonators embedded in a dielectric elastic medium which is used as a platform to allow continuous elongation of the system. We design the metasurface so that the phase of the reflected waves is a hyperbolic function of the coordinate, and the amplitude of the reflection is almost constant. The numerical

simulations of the designed structure show that the focal distance increases linearly as a function of the metasurface elongation. We fabricated the metasurface which operates in the microwave frequency range, and experimentally observed tunable focusing properties of the structure. Our proposal demonstrates that it is possible to use elastic smart metamaterials as a platform for new tunable electromagnetic devices for electromagnetic beam steering and shaping.

9668-139, Session 6C

Investigations on the influence of laser fluence and wavelength in the inclusion of zinc dust in Cu-Al for the development of Cu-Zn-Al shape memory alloy using laser assisted alloying

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CuZnAl shape memory alloy can be an excellent alternative to NiTi SMA owing to its high heating and cooling rate, high energy efficiency, high damping capacity and low cost. Synthesizing CuZnAl thin film and subsequently laser annealing it, may lead us to spatially distribute the SMA properties and can be used as an actuator, while untransformed material is passive and acts a restoring force . In this regard, a novel approach of developing a CuZnAl thin film using metal fine powder combined with laser annealing is being carried out.

CuAl was deposited layer by layer using physical vapour deposition on glass substrate and the thickness of the film was maintained according to the composition of the shape memory alloy (400 nm- 70.3 %, 26 nm – 5.6%). The thin film was annealed using a nanosecond Nd:YAG laser with three different wavelengths and varying fluence. The as obtained samples were characterized using SEM, EDAX, and XRD. Zinc dust was added to the annealed film in weight proportions and further it was treated with laser for the alloy formation. Laser parameters such as wavelength and fluence were studied for the alloying process. The samples were characterized using DSC for identifying the shape memory characteristics such as transformation temperature of different phases.

9668-140, Session 6C

Influence of laser fluence and substrate temperature on the laser induced forward transfer (LIFT) of ZnO and Sb doped ZnO nanostructures to the flexible PET to realize P-N junction for the flexible UV LED device development

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Synthesizing ZnO nano structures on the flexible PET substrate is challenging task. Laser induced forward transfer is one of the promising technique in transferring thin films without any damage to the structure. This technique can be efficiently employer to transfer ZnO nano structures to the Flexible PET Sheets. In this research work an attempt has been made to transfer, N-type ZnO and Sb doped ZnO to the Flexible PET substarte so as to realize P-N junction for UV LED device development.

N-type one dimensional ZnO nano structures were fabricated using a simple hydrothermal technique by considering KmnO4 as catalyst on an ITO coated glass substrate. The Sb doped ZnO nanostructures were synthesized using Nano particle assisted pulsed laser deposition (NAPLD) on a Sb coated Glass substrates. These two set of samples were transferred to a ITO coated PET substrate. Nd:YAG laser with a of 532 nm was used. The transfer was performed by varying a laser fluence ranging from 30-300 mJ/cm2 and a substrate temperature from 50-300 ?C.

A particle dynamics analysis were used to investigate the velocity of the blow off structure by using a sheet beam coupled with an ICCD system. The as transferred Nano- structures were characterized through SEM, XRD, PL, to investigate it surface morphology, structural and optical properties. To investigate the Adhesion of the film Scotch test analysis was performed. It was observed that optimum laser fluence for transferring ZnO to the pet sheet is 80mJ/cm2.

9668-141, Session 6C

Optimisation for Schottky electrode

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The geometry of the Schottky contact electrode is important in the design of Schottky power diodes. This work focuses on the optimum shape of the Schottky contact geometry using finite element modelling. The investigation considers the typical situation where the contact is smaller than the substrate area. Simulations were run with the different shapes ranging from perfect circle to perfect square with the size of the diode and the distance between the edge of the diode and the edge of the Schottky contact as a constant. The different models were examined for the occurrence of the maximum current density and hence breakdown regions at current density approaching the critical value for breakdown due to high current density. There was an optimum geometry determined for the highest current that the diode could deliver. The results were conclusive that the optimum geometry for the Schottky contact should be neither perfect square nor perfect circle, but an exact geometry in between. This optimum geometry gives the optimum distribution of current density around the edge of the Schottky contact. Investigation is done using Synopsis TCAD. The forward and reverse bias situations were investigated to optimize the electrode geometry and determine where substrate material effects are more significant than electrode geometry.

9668-144, Session 6C

Optical properties of refractory TiN, AlN and (Ti,Al)N coatings

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Titanium nitride is a golden-colored semiconductor with metallic optical properties. It is already widely used in room temperature spectrally-selective coatings. In contrast, aluminum nitride is a relatively wide-band gap, non-metallic material. Both nitrides have exceptional thermal stability, to over 1000 °C but are susceptible to oxidation. We will show here that composite coatings consisting of both materials have considerable potential for application as spectrally-selective coatings at elevated temperatures. In particular, we examine the metastable material fcc-(Ti,Al)xN produced by magnetron sputtering and show how it can be heat-treated to yield a composite microstructure of TixN and AlxN. The effective dielectric function of this material can be tuned over a wide range by manipulation of its two-phase microstructure. This provides a strategy to assemble complex dual-phase microstructures using a 'bottom-up' approach. The results are compared to those achievable by conventional, 'top-down', planar optical stacks comprised of alternating layers of TixN and AlxN.

9668-145, Session 6C

Gyroid based nanostructures with cubic symmetry for on-chip photonic applications

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Gyroid is a kind of periodic minimal surface derived from the wing scales of the butterfly Callophrys rubi, whose geometry is corresponded to the well-known srs network in solid chemistry. Theoretical studies have revealed that single-gyroid nanostructures exhibit significant circular dichroism, based on which, a miniature circular beamsplitter has been experimentally demonstrated by laser direct writing (LDW). Furthermore, the optical properties can be tuned by intertwining multiple srs network, e.g. dielectric 8-srs composite is predicated to possess high optical activity. Therefore, gyroid based nanostructures provide a platform for on-chip light manipulation.

For on-chip applications where the light propagates in the horizontal plane, the cubic symmetry of the nanostructure is essential to ensure the same optical response along all the three axes. Unfortunately, LDW method suffers from an elongated cross-section of the fabricated rods. To address this issue, we apply a galvo-dithered LDW method to eliminate the axial elongation. Not only the geometry of the rods cross-section, but also the mechanical stability is improved due to the cubic symmetry. As a proof-of-concept demonstration, we fabricate a system consisting of 1-srs circular beamsplitter and 8-srs optical rotators, suggesting an avenue towards gyroid based structures enabled on-chip photonic circuits.

9668-104, Session 7A

Bio-functionalisation of polyether ether ketone using plasma immersion ion implantation

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For orthopaedic implantable devices to provide long-term viability, they must satisfy the dual demands for biological and mechanical compatibility. Current implantable devices made of titanium are biologically benign, but are too rigid and lead to bone degradation via stress shielding[1]. Efforts to alter the elastic modulus of implantable devices to values similar to bone have met with limited success[2]. Polyether ether ketone (PEEK) is a promising candidate for the next generation of orthopaedic implants because of its mechanical similarity to bone. PEEK however, produces a bone-implant interface strength that is inferior to titanium[3] – a critical determinant for orthopaedic implantation. In this study we use Plasma Immersion Ion Implantation (PIII) to activate a surface layer of PEEK by introducing radicals that covalently bind proteins to improve bone-implant interface strength and integration.

PIII treatment modifies the PEEK by bombarding the surface with nitrogen ions. These ions disrupt a surface-layer of PEEK by breaking bonds and generating radicals. The radicals are capable of moving throughout the modified structure, and can diffuse to the surface and covalently bind proteins in a robust and reliable way. The immobilised protein retains its biological activity and cannot be displaced through vigorous washing. This treatment therefore produces a surface that can cloak the underlying PEEK structure so that bound proteins can interact favourably with cells to improve the bone-implant interface.

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9668-105, Session 7A

Micro-scale resolved mechanical property variation of the yttria partially stabilised zirconia-porcelain interface in dental prostheses

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Yttria Partially Stabilised Zirconia (YPSZ) is a ceramic which has increasingly found use in dental prostheses due to its high toughness, appealing aesthetics and biocompatibility [1]. In dental prosthetics, YPSZ is coated with porcelain in to produce a more appealing finish and to reduce the hardness of the tooth, thereby minimising wear on existing teeth. Despite these benefits, this process is known to lead to near interface chipping of the porcelain veneer [2].

Recent studies of the YPSZ-porcelain system have revealed the importance of YPSZ phase transformation [3], porcelain creep [4] and residual stress [5] within the first few microns from the interface. One of the most promising approaches for improving understanding of the complex phenomena that play out in this region is the elaboration of micro-mechanical models. These must rely on the precise knowledge of the microstructure and mechanical behaviour in this region.

We present the results of three micro-scale spatially resolved studies (<5?m) performed on the near-interface region (±100?m) of a completed prosthesis:

1. Flat punch compression of micropillars produced by Focused Ion Beam (FIB) milling [6]. This allows evaluation of the loading modulus and yield strength behaviour.

2. Berkovich tip nanoindentation and splitting of FIB milled micropillars [7] to estimate fracture toughness.

3. Cube corner and Berkovich nanoindentation to identify the elastic modulus and hardness of the YPSZ and porcelain regions.

Mechanical property variations were found to be highly localised (<20?m) to the near-interface region, thereby providing improved insight into the failures observed at this location.

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9668-122, Session 7A

Wafer-scale epitaxial graphene on SiC for sensing applications

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Large area graphene may be fabricated either by CVD using metals or from silicon carbide (SiC). The small domains in metals have shown to create challenges in obtaining high quality graphene, while SiC has demonstrated larger domains and high quality performance, for example in quantum Hall resistance standard. The high quality makes is possible to detect even small changes in resistivity upon exchange with molecules, and thus epitaxial graphene is very promising in sensors. In addition, the strong bond of graphene with the SiC makes it very robust in any environment. The epitaxial graphene in flat, large-area substrates (up to 100 mm in diameter) provides advantages to fabricate sensors using standard semiconductor micro/nano wafer processing without the need for any layer transfer like in CVD growth. In particular, both SiC and graphene have demonstrated excellent biocompatibility in in-vivo and in-vitro studies with no cytotoxicity responses. Combination of their biocompatibility and substrate-inferred processability makes graphene/SiC a highly attractive material for bio sensing applications.

This work compares various sensor approaches based on the graphene grown on 2" 4H SI-SiC. The graphene's structural, optical and electrical properties were verified by AFM, SEM, TEM, FTIR and current-voltage (I-V) characteristics utilizing transmission-line method (TLM) structures. The results reveal good uniformity of the graphene by the wafer scale mapping. A few sensor examples will be described in this paper, one of them is a glucose sensor for early diagnosis and monitoring of diseases. In addition, integration of the graphene with ZnO tetrapods and Au nanostructures is also explored in order to pave the way for possibilities to enhance the sensitivity of the biosensors.

9668-123, Session 7A

Conductivity and electrical studies of plasticized carboxymethyl cellulose based proton conducting solid biopolymer electrolytes

Mohd Ikmar Nizam Bin Mohamad Isa, Noor Azniza Mohd Noor, Univ. Malaysia Terengganu (Malaysia)

In this paper, a proton conducting solid biopolymer electrolytes (SBE) comprised carboxymethyl cellulose (CMC) as a polymer host, ammonium thiocyanate (NH4SCN) as a doping salt and ethylene carbonate (EC) as a plasticizer. The plasticized CMC-NH4SCN SBE system has been prepared via solution casting technique. Electrochemical Impedance Spectroscopy (EIS) was carried out to study the conductivity and electrical properties of the plasticized CMC-NH4SCN SBE system over a wide range of frequency between 50 Hz to 1 MHz at temperature range 303-353 K. Upon addition of plasticizer into CMC-NH4SCN system, conductivity increased from 10-5 to 10-2 Scm-1. The highest conductivity was obtained by the electrolyte contained 10 wt.% of EC. The conductivity of plasticized CMC-NH4SCN SBE system by various temperatures obeyed Arrhenius law where the ionic conductivity increased as the temperature increased. The activation energy, Ea was found decreased with enhancement of EC concentration. Dielectric studies for the highest electrolyte obey non-Debye behavior. The conduction mechanism for the highest electrolyte was determined by employing Jonsher's universal power law and thus, can be represented by the quantum mechanical tunneling model.

9668-124, Session 7A

Tuning the surface chemistry of plasma activated coatings deposited on zirconium substrates

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Zirconium-based alloys are promising materials for orthopedic prostheses and dental implants due to their low toxicity, superb corrosion resistivity, and favourable mechanical properties. The bare surfaces of metals may, however, trigger foreign body response, inflammation, or infection; causing extensive costs and discomfort for patients. The integration of such bio-implantable devices with local host tissues can strongly be improved by the development of a nano-structured plasma activated coating (PAC) that immobilises bioactive molecules. The surface chemistry of PAC is, however, critically important as it plays a key role in affecting the surface free energy (SFE), which affects the conformations and thus functionality of bioactive molecules at the surface. This study explores the influence of plasma polymerisation conditions on the surface chemistry and hydrophobicity of PAC coatings deposited on zirconium substrates. X-ray photoelectron spectroscopy (XPS) data revealed that by tuning the nitrogen to acetylene ratio of the precursor gas, PAC surfaces with a range of nitrogen concentrations (0 to ~ 25%) are obtained. Such variations in surface chemistry resulted in a range of SFEs from (50.8 ± 0.51) to (64.28 ± 0.72) mJ.m-2. According to XPS and contact angle measurement findings, high RF input powers and bias voltages increased the SFE via the introduction of polar oxygen-containing groups to the surface. It has been shown that by carefully manipulating the plasma polymerisation parameters, carbon-nitrogen coatings with tailored surface chemistries and SFEs can be produced.

9668-151, Session 7A

Application of novel iron core/iron oxide shell nanoparticles to sentinel lymph node identification

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Introduction: Current 'gold standard' staging of breast cancer and melanoma relies on accurate in vivo identification of the sentinel lymph node. By replacing conventional tracers (dyes and radiocolloids) with magnetic nanoparticles and using a handheld magnetometer probe for in vivo identification, it is believed the accuracy of sentinel node identification in non-superficial cancers can be improved due to increased spatial resolution of magnetometer probes, and additional anatomical information afforded by MRI road-mapping. By using novel iron core / iron oxide shell nanoparticles, the sensitivity of sentinel node detection can also be increased due to increased magnetic saturation compared to traditional iron oxide nanoparticles.

Methods: A series of in vitro magnetic phantoms (either iron core / iron oxide shell or iron oxide nanoparticles in both dried and colloidal states) were prepared to simulate magnetic particle accumulation in the sentinel lymph node. A novel handheld magnetometer probe was used to measure the relative signals of each phantom, and the results compared to in vivo data from a previous large animal study.

Results: While iron core / iron oxide nanoparticles offer larger magnetic saturations compared to magnetite nanoparticles (310 %), a more pronounced magnetic hysteresis reduces the efficacy of these novel particles in magnetic field switching applications (i.e. magnetometer probe).

Conclusion: By modifying the core / shell ratio of these particles and the switching frequency of the probe, the magnetometer probe's sensitivity of detection can be increased, improving the accuracy of sentinel node detection: an important milestone for application to non-superficial cancer staging.

9668-224, Session 7A

Determination of effect factor for effective parameter on saccharification of lignocellulosic material by concentrated acid

Ali Arasteh Nodeh, Islamic Azad Univ. of Najafabad (Iran, Islamic Republic of); Sina Aghili, Islamic Azad Univ. (Iran, Islamic Republic of)

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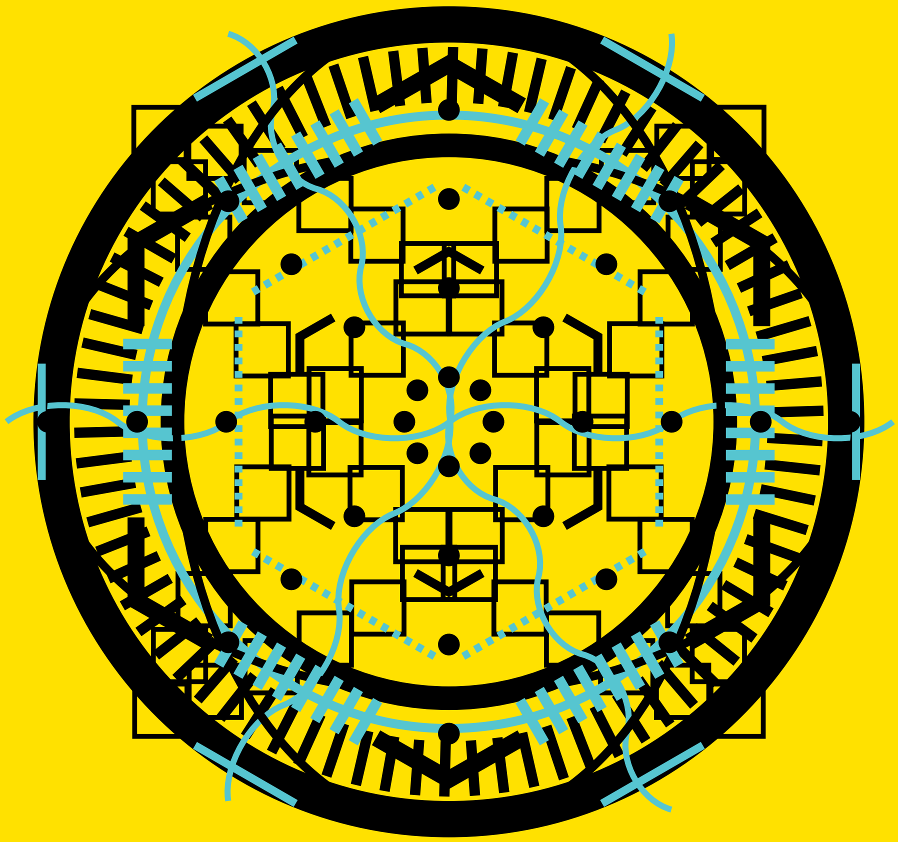

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